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1945—1946

THE year almost closed has seen the victorious conclusion of the war with Germany and Japan, the discovery and use of atomic power, and, for the first time in the history of Britain, with a clear majority, a Labour government entrusted with the political control of this country. Each alone would be momentous and would have important significance historically, but together, in one year, their combined importance on the future of mankind and of this country in particular, make the year one of the most important experienced for many generations.

> WE extend to all our readers our Sincere Greetings and Best Wishes for a Happy Christmastide ; may the New Year bring all you seek.

This year will be regarded as the concluding year of one of the most violent and brutal periods experienced in the world's history. In the early years of the war, Germany, and later, Japan, went from success to success, spreading fear, misery and death in their path. Gradually, however, the democratic nations built up their forces and ultimately achieved victory. But victory has only been won at great cost in blood and treasure. Millions of people have been sacrificed or deprived of all that makes life worth-while to satisfy the lust for power, and, while few will grudge the natural desire to celebrate the first peaceful Christmas for six years, it must not be overlooked that the fundamental moral values, for which we as a nation, entered the struggle, are still to be won. The war has disorganised the conventional way of life and has given all ages and all sections of society, unfamiliar situations. In times of peace, cultural changes and the application of scientific developments are slow, but war accelerates the speed of evolution and makes wide-scale planning more difficult.

The discovery of atomic energy is of tremendous import. It will ultimately provide another source of power for the good or ill of mankind. For generations, wind, water and fuel have been regarded as the main agents for supplying energy ; the harnessing of the sun's rays and of tidal waters have been used to a very limited extent ; but the possibilities of atomic energy have not yet passed the imaginary stage. It is noteworthy that Sir John Anderson, who is chairman of the Advisory Committee on Atomic Energy, referring to this subject in a recent address before the Manchester Joint Research Council, said that nothing has been discovered to justify the expectation that the energy released by an atomic explosion could be used industrially. The only method which existing knowledge suggests as practicable depends upon the conversion into heat of the energy released by a controlled process of nuclear fission. There is no difficulty in realising this in practice but there are practical problems arising out of the very high temperature and the special controls required to prevent corrosion and the rapid disintegration of the whole system. There is also the new hazard arising out of the intense and very dangerous radiation by which the nuclear reaction is attended. This means elaborate shielding and a complete system of remote control. Obviously, there is much to be done and further discoveries to be made before atomic energy can be applied industrially, but, in view of the progress so far made, the time may not be far distant when the major difficulties attached to its use will be solved.

In Britain, under a Labour Government, fundamental changes are being made in the country's economy. To some extent these changes are due to the weakened condition of our financial resources. Investments in countries overseas which had accumulated over past decades have been almost wholly absorbed to achieve victory ; everything was sacrificed to that end, with the result that, in planning recovery, the manufactured goods, of which we are in great need, are being sent overseas in exchange for food and raw materials. The loan from the United States, which is under discussion at the time of writing, if agreed upon, should be of great assistance to Britain in overcoming her immediate difficulties and in building up a prosperous future, but the terms seem to be hard and take no account of the sacrifices Britain has made to bring about victory.

The only salvation for this country in the future is hard work. Our people must learn to work efficiently, a fact which has been distorted by the work and wages condition of war time. Conversion from war to peace conditions of employment will include realisation that war conditions are not normal. Work habits need to be improved. On the other hand, works should be equipped with modern plant and the best possible use made of mechanical devices. In some instances, modern plants which have been engaged wholly on war work are in process of change to peace-time products. In these cases much progress has already been made. In a number of basic industries, however, war demands prevented the installation of new plant and interfered with developments. In these cases, considerable capital expenditure is necessary to enable work to proceed efficiently. A notable example is the iron and steel industry. Already very comprehensive plans have been formed, some of which are being carried out. A recent announcement among many refers to a new universal beam mill, the first in this country, and a new steel plant which are to be built on Tees-side by Dorman, Long and Co. Ltd., at a cost of £8 million. This announcement is typical of the progressive policy of British

industry generally. Changes are being made methodically and, although the speed of conversion seems to be slow, it is gathering impetus and 1946 shows signs of being a successful year.

It is gratifying to note that of the fundamental changes contemplated, that of education and training occupies a high position. The war has shown what can be accomplished by organised effort in which scientists are directly concerned. We have discussed some of the remarkable results of intensive research under the stimulus of war ; it is necessary that the efforts of these scientists should now be directed to the needs of peace.

But even with improved educational facilities and the most modern plant in our factories, there is need for a greater measure of teamwork, between management and labour. Efforts are being made to establish team work amongst the nations, but how can success be achieved if workers of individual nations cannot reach agreement among themselves. It is probable that this trend of goodwill, which is just visible, may become the basic source for establishing the new world all seek.

Institution of Metallurgists

IN our February issue last, a preliminary announcement appeared concerning the formation of a professional body representative of metallurgists in all branches. The demand for action in this direction had been persistent for some years, during the war in particular, the need of a special organisation of qualified metallurgists became more pronounced. However, it is probable that the demand would have remained unsatisfied for many more years had not the initiative been taken by a group of well-known and recognised metallurgists. Under the direction of this group steps were taken to form such a body to be known as the " Institution of Metallurgists " and to be registered as a company limited by guarantee. The Memorandum of Articles drawn up has now been approved by the Board of Trade and at a meeting held in London on November 28, 1945, this new Institution was formally inaugurated.

The President is Dr. Harold Moore, C.B.E., who was for many years director of metallurgical research at the Armament Research Department, Woolwich, and later director of research for the British Non-Ferrous Metals Research Association. Before a widely representative gathering which met at the headquarters of the Iron and Steel Institute and the Institute of Metals, Dr. Moore gave an account of the formation, constitution and objects of the new Institution, and described the contributions it can be expected to make to metallurgical progress. The formation of an Institution has been mooted at various times and within the past two or three years there has grown up a strong feeling, especially amongst younger metallurgists, that metallurgy as a profession should be recognised and safeguarded. Modern metallurgy is a comparatively new profession, including as it does, not only the older aspects of the extraction and refining of metals but also their treatment and use in the form of innumerable alloys as well as of the relatively pure metals. In recent years metallurgists field of work has greatly expanded and now includes the many methods of forming and shaping metals and all the vast technique of mechanical and thermal treatment, of behaviour in service and of physical metallurgy as we know it to-day.

The science has been well served by organisations that meet for the reading and discussion of scientific and technical papers of a metallurgical character, but, apart from the Institution of Mining and Metallurgy, which is concerned primarily with the mining and extraction of non-ferrous metals, none of these bodies is a qualifying institution. There has been a strong desire to rectify this position by the formation of a new organisation admitting only qualified metallurgists to membership and having functions supplementary to, but independent of, those of the existing metallurgical institutes. Steps were therefore taken by the Councils of the Iron and Steel Institute and the Institute of Metals which have resulted in the incorporation of the new body. To these Institutes, Dr. Moore expressed the appreciation of the professional organisation for the great amount of help given, particularly by members of the respective staffs.

In the absence of Mr. Arthur Dorman, President of the Iron and Steel Institute, who was on urgent business elsewhere, the Hon. R. G. Lyttelton welcomed the formation of the new organisation on behalf of the Iron and Steel Institute ; Dr. W. T. Griffiths, President of the Institute of Metals, Dr. J. H. Jenkin and several other representatives of kindred associations expressed the need for the new Institution and gave it their blessing.

Primarily the Institution will bring within one professional body qualified metallurgists engaged in production, research, teaching, consulting work, inspection and other metallurgical activities associated with any branch of industry. It will establish qualifications that will be the hall mark of competence in the science and practice of metallurgy. It will set high standards for admission as Fellows, Associates and Licentiates. It will promote the welfare of the profession, improve and maintain its standing, and co-operate with all organisations seeking to advance the study of metallurgy. It will expect a high standard of professional conduct among metallurgists, promote better education and training, and will operate an appointments register.

The subscription rates are for Fellows, £3 3s. ; for Associates, £2 2s. ; and for Licentiates £1 5s., with reciprocal reduction for joint members with the Iron and Steel Institute and the Institute of Metals to £2 12s. 6d., £1 11s. 6d. and £1 1s., respectively. No entrance fee will be charged for the time being.

The new body bids fair to achieve in a very short time its objects of establishing an appropriate status for competent metallurgists and of ensuring adequate recognition of the profession. The first Council, necessarily gathered together by nomination and co-option, is a representative selection of prominent metallurgists who will, however, retire at the Annual General Meeting of 1946. A new Council will then be elected by the membership in the normal democratic way. Adequate liaison with the Iron and Steel Institute and the Institute of Metals is provided by the joint use of 4, Grosvenor Gardens as headquarters and the services of Mr. K. Headlam-Morley as Secretary, from whom full particulars can be obtained regarding regulations for admission.

The Mechanism of Brittle Fracture

By G. Stanley Smith, B.Sc., A.R.I.C.

Evidence of the actual process of fracture of brittle materials is not easy to obtain, but recent study of the subject has introduced a new conception of fracture which assists the acceptance of a theory developed twenty-five years ago. Various aspects of the subject are reviewed and particular attention is directed to recent work the results of which appear to establish, with certain kinds of materials, the role of external and internal defects during fracture and the order of formation of the parts of the new surfaces.

IN the case of materials of simple structure it is possible to calculate the attractive forces between the atoms across a given plane of rupture from the values of the electrical charges and distance and to obtain, in this way, a figure for the mechanical energy of rupture which can be used for comparison with the tensile strength as determined experimentally by means of a testing machine. Calculations of the cohesive forces may also be made on the basis of other theoretical considerations, from the surface tension which is assumed to be of the same order of magnitude as that of the liquid material, or from the lattice energy deduced from measurments of the energy required to vaporise a certain number of atoms from the crystals.

All such theoretical calculations lead to the surprising result that every material so studied has a " theoretical " strength which is a hundred or more times the " apparent " strength. This enormous difference between the potential and the actual strength of a body has represented during the lastfew years one of the major problems in the physics of solids and it must still be counted as one of the unsolved problems of science. It is, in addition, a matter of considerable practical interest since if the reason for the weakness of a material can be established it may suggest hitherto untried methods of treating materials to make them stronger.

Amongst the theories of weakness that of Griffith[1] holds first place. It dates from 1920 and appears to be the earliest. Griffith made the suggestion that fracture starts at a weak place—a rudimentary crack—on the surface of a sample subjected to test and proceeds by successive development of the crack across the sample. He supposed that there are present on the surface of every sample minute cracks which alter the distribution of the stresses which arise under the influence of the applied forces. At certain of these rudimentary cracks the extra stress could attain a magnitude corresponding with the theoretical value for the strength of the material, although the average stress might be very low. Under these conditions a crack would begin to grow where the stress was greatest and would lead finally to the fracture of the whole sample at an average stress which was quite small compared with the theoretical strength (Fig. 1).

Regarding stress concentration it can be shown[2] that the stress at the ends of the major axis of an elliptical hole in a plate subjected to tension in a direction at right angles to this axis is given by the equation :—

$$s_{max} = s_o \left(1 + 2b/c\right),$$

where b and c are the lengths of the major and minor axes, respectively, and s_o is the uniform stress at the ends of the plate. If c is made very small in comparison with b then s_{max} becomes extremely great and in the limiting case would be infinite. Hence, if a crack is considered to be an ellipse, the minor axis of which is negligible in comparison with the major there is no mathematical limit to the stress concentration at the ends when the crack is perpendicular to the stress axis. Similar reasoning indicates that when the crack is in line with the stress there is no stress concentration, for s_{max} tends to equal s_o as b approaches 0.

When a plate of brittle material is stressed in tension, high stress concentration at holes, notches and places where changes in cross-section occur remains up to the breaking-point. In the case of a ductile material, the growth of stress is impeded by flow, plastic deformation or by some other process of regrouping and the distribution of stress tends to become more uniform. A notch or groove in such a material increases the strength (maximum load divided by original cross-section) in many instances, a result which was established as long ago as 1861 by Kirkaldy,[3] but a notch in a bar of brittle material tends to have the opposite effect. For these reasons, cracks would be expected to exert a much greater

Fig. 1.—Stress concentration caused by a crack.

influence on the strength of a brittle material than on that of a ductile material. It was mainly from his studies of the fracture of a brittle material—glass—that Griffith developed his theory, but the idea of explaining the low, experimental values of the strength of various other materials has entered into several theories of fracture.

A fresh conception of brittle rupture was put forward a short time ago by Murgatroyd.[4] He considers that the phenomenon of delayed rupture, which is shown to a

1 A. A. Griffiths. *Phil. Trans. Roy. Soc.*, 1920, **221**, A, 163.
2 E. G. Coker and L. M. G. Filon. " Treatise on Photo-elasticity," 1931; S. Timoshenko and G. H. McCullough. " Elements of Strength of Materials," 1938.

3 D. K. Clark. " Rules, Tables and Data for Mechanical Engineers," 1890, Page 574.
4 J. R. Murgatroyd. *Nature*, 1944, **154**, 51.

marked degree by glass, cannot easily be explained on Griffith's theory alone. He suggests that glass may consist of an elastic matrix containing small pockets of "quasi-viscous" material which would take the place of Griffith's flaws. When the glass is subjected to stress a stress concentration, increasing with time, would occur in the matrix with relaxation of stress in the viscous material which carries the initial load. A ductile body could be pictured as made up of viscous material with elastic pockets as inclusions and a brittle body as mainly elastic but containing viscous pockets as inclusions. This theory has been opposed by Orowan,[5] who maintains that the Griffith crack theory is adequate to explain the decrease of strength with time. Adsorbed films are known to be present on glass surfaces and when film forms inside a surface crack the crack is made more dangerous. During rapid fracture this film would not have time to diffuse to the bottom of the crack and assist in opening up the crack further. On the other hand, such diffusion could occur during slow fracture and hence the effect of time would naturally be shown as a lowering of the strength. Orowan points out further that a correct mathematical treatment of Murgatroyd's model would lead to the conclusion that the viscous pockets and not the elastic matrix constitute the greater part of glass.

The reason for the success of Griffith's theory has been mainly its simplicity and the greater difficulty of explaining the results of experiments designed to test it on any other basis. The very existence of sub-microscopic surface cracks was purely a matter of conjecture for many years. It was only in 1937 that they were revealed for the first time by Andrade and T'sien.[6] These investigators succeeded in developing and making visible the minute surface cracks on hard-glass tubes by means of sodium vapour. Previously, all the evidence had been indirect. Thus Ioffe (in 1923) found that the tensile strength of a sample of rock salt tested in hot water was 30–300 times higher than that of a sample tested dry. The increased value in hot water was explained as a result of the solvent action of the water in removing the surface containing the rudimentary cracks which were supposed on Griffith's theory to govern the strength of the rock salt in its normal state. Again, Orowan[7] demonstrated that a sheet of mica was much stronger in the middle than at the edges, which, presumably are weakened by invisible cracks. Such experiments built up a strong case for supposing that a brittle material fractures because of the presence of a minute surface flaw but gave little information about the method of propagation of the crack during fracture or of the actual mechanism of rupture.

Some light has now been shed on this matter by the Russian physicist, A. P. Aleksandrov,[8] as a result of a careful examination of the surface of fracture of a number of amorphous materials. His explanation of the nature of fracture is fully in accordance with Griffith's theory and takes into account both internal and external cracks of minute size which may be present in a material. These internal cracks, if present, appeared to have only a minor influence on the strength of the materials examined by Ioffe and Orowan—rock salt and mica—but certain experiments on glass and quartz which were

5 E. Orowan. *Nature*, 1944, **154**, 341.
6 E. N. da C. Andrade and L. C. Tsien. *Proc. Roy. Soc.*, 1937, **159**, A, 346 ; *Engineer*, 1941, **171**, 300.
7 E. Orowan. *Z. Physik*, 1933, **82**, 235.
8 A. P. Aleksandrov. Herald of the Academy of Sciences, U.S.S.R., 1944, 7-8, 51 (In Russian).

carried out by Zhurkov point strongly to their existence and to the possibility that they play a definite role in the process of fracture. Zhurkov discovered that when the surface of glass or quartz threads were removed by means of hydrofluoric acid attack to a depth of a few microns, the strength of the material was raised 6 to 10 times but, in contrast with the Ioffe effect where the increased strength of the rock salt disappears quickly after the drying of the samples, the strength of the etched samples of glass and quartz was retained for an indefinite period after drying provided that the surface was protected from damage. The surface was, in fact, very sensitive ; merely touching it with anything solid, such as wood, glass, paper, etc., was sufficient to restore the original, low strength of the material. It was concluded that the technical strength of glass and quartz is determined by the presence of surface defects of chance origin. Zhurkov then carried out tests during the etching in hydrofluoric acid, applying the load throughout the whole time of etching. In this case there was no strengthening effect and the usual low values for strength were obtained. It was, therefore, necessary to suppose that the weak places, considered to be sources of failure, were spread out over the whole volume of the glass as well as on the surface ; from time to time, during the etching, internal defects are laid bare, as the original defects on the surface are removed and these
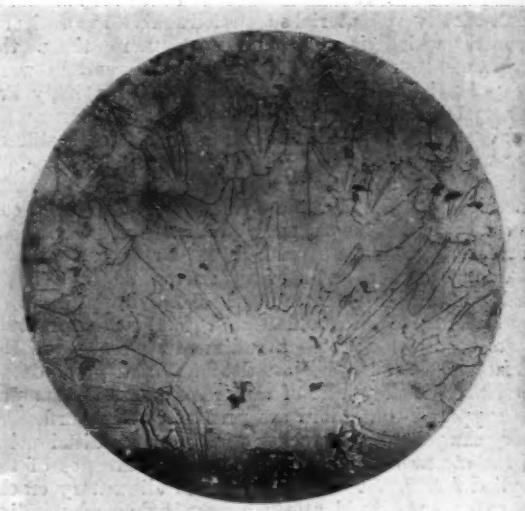
Fig. 2.—Portion of fractured surface of Perspex.
(Reduced to about ¾ actual size). x 100.

cause failure to take place before the acid has had a chance of removing them. Thus the surface defects and the internal defects would seem to be of the same order of magnitude, but some explanation is required as to why the defects which lower the strength so considerably in practice are those on the surface rather than the similar ones inside the sample. An answer to this question was given by Grebenschikov as a result of his work on the films of gelatinous silica which usually cover the surface of glass and quartz and are caused by the action of water. These films are porous and swell easily in various liquids, particularly in water. The gel covers the whole surface of the glass including the surfaces of the cracks and because it occupies a greater volume

than the glass from which it has been formed there is a pressure exerted on the sides of these surface cracks. They are, therefore, subjected to additional stresses and so the critical stress at which cracks begin to grow during deformation of the material under load is attained much earlier at the surface than in the interior.

Aleksandrov's examination of fractured surfaces indicated that two distinct zones, one smooth and the other scaly, could be observed in all cases. When the transition from the smooth to the scaly zone was viewed under a microscope the scaly part was found to be made up of hyperbolas, some of which were very well defined, disposed in such a way that the head or vertex of each one was directed towards the centre of the smooth zone. The number of these hyperbolas increased with the distance from the smooth zone and they became superimposed on one another, thus giving the scaly appearance. The occurrence of these hyperbolas has been confirmed by the present writer (a photograph of part of the surface of a fractured tensile test-piece of perspex is shown in Fig. 2.)

Each hyperbola traces a line of slip and represents a step in the process of fracture. Their origin is easily explicable on the assumption that minute flaws are present before fracture across the whole section of the sample. If this is the case, there will be a stress at each flaw during deformation under load which will exceed the average for the section. From the most " dangerous " flaw, i.e., the defect where the stress is greatest, there will begin to grow a crack in a plane perpendicular to the axis of the normal stresses and, as the average stress increases, cracks will begin to develop from other defects in accordance with the magnitude of the excess stresses at those defects. Gradually growing, they will meet and the line of contact of neighbouring cracks will appear as a slip in the surface of fracture. It is reasonable to suppose that these cracks are circular, from which it follows that the slip lines are hyperbolas. The surface of fracture is thus a diagram whereon it is possible to read the order in which the various defects entered into the process of fracture and the speeds with which cracks developed from them. This point is illustrated in Fig. 3. If cracks were to start growing from two centres at the same time and with similar speeds then the line of contact would be a straight line, but if one of the cracks starts later than the other the line of contact must be a hyperbola, the angle between the asymptotes being smaller the later the commencement of growth at the second centre, i.e., the lower the excess stress.

It appears clear that in the case of plastics the external and internal non-homogeneities are of roughly equal significance, provided the surface is reasonably clean and undamaged, but in the case of glass the excess stress at the surface defects is considerably greater than that at the internal defects, as was indicated above and, in fact, it is very difficult to observe hyperbolas on a surface of fracture ; they degenerate into barely noticeable double lines.

Thus Aleksandrov's discovery serves to establish in connection with certain kinds of materials the role of external and internal defects during fracture and the order of formation of the parts of the new surface.

For the occurrence of local excess stress it is necessary, as Aleksandrov points out, that the material should contain inclusions or heterogeneities possessing mechanical properties, such as the elastic modulus or the yield strength, different from those of the main material. The question of the origin of these heterogeneities is of fundamental importance in connection with the problem of discovering if it is possible to prepare materials with strengths approximating to the theoretical values under technical conditions. At the present time, however, there are still only a few definite achievements to be recorded but there are many possible lines of attack. There seems to be little doubt that these heterogeneities must have microscopic rather than molecular dimensions.

It has been suggested that, in certain cases, heterogeneities acting as defects on the surface of a sample are brought into being during the process of plastic deformation. Stepanov, while studying the brittle fracture of mono-crystals of rock salt, noticed that fracture is always preceded by glide in greater or lesser degree and that the surface of fracture invariably runs from a surface " fault " produced by slip, which he called a " hearth " of excess stress. When the sample of rock salt was treated in such a way that slip on the working part of the sample was difficult, he succeeded in obtaining a considerable increase of strength. The phenomenon of twinning which may make an appearance during the deformation is also considered to lead to hearths of excess stress. Another phenomenon is " kinking," which Orowan[9] noticed with mono-crystals of metals stressed in compression. This, Orowan states, must be distinguished from flexural glide. In the latter the lamellæ are curved and the compressed side of one lamella is next to the extended side of another and the dislocations produced by the inability of the lattices of one lamella to fit on those of another are fairly evenly distributed. In kinking, on the other hand, the glide lamellæ remain plane except near to the plane of kinking and consequently the dislocations are concentrated on the plane of kinking.

It appears, therefore, that defects in mono-crystals which lead to rupture may be created in the deformation process itself.

In poly-crystalline materials such heterogeneities exist in great quantity earlier. Consequently, it would seem impossible in principle to obtain parts or articles in crystalline material where the formation of hearths of local stress could be avoided.

In amorphous materials like glass the hearths of excess stress on the surface and in the depth of the material are not created as a result of deformation. This is proved by the fact that the strength of glass is improved by etching and the increased strength is preserved for an


Fig. 3.—Formation of hyperbolas.

indefinite period. Samples made by completely different technological processes possess very nearly the same strength. One may infer, therefore, that the formation

9 E. Orowan. *Nature*, 1942, 149, 643.

of hearths of excess stress is an effect inherent in the building-up of the structure of the material.

From this it follows that we cannot expect to obtain materials under ordinary technical conditions which possess the " theoretical " strength. Nevertheless, there are various ways which may be used to prepare stronger materials.

Taking the case of a material the technical strength of which is conditioned by existing surface cracks wedged open by substances which are normally present in them, we can, by dissolving away the surface, raise the strength, perhaps 5 or 10 times. The new surface, however, will probably be so sensitive that such a method would be of value only if the material could be used in enclosed constructions. Thus, in instruments employing quartz suspensions one may safely increase the weight of the system five times by using a quartz thread which has been etched. Two other possible applications of etching for the purpose of increasing strength are referred to by Aleksandrov—the manufacture of thin glasses for windows of vacuum vessels for emission of rays and the preparation of elastic manometric partitions separating gaseous or liquid volumes at different pressures.

A second method of raising the strength of parts made from such materials involves rapid cooling of the surface from some suitable higher temperature whereby a compression stress may be obtained in the surface layer. In this the surface defects are not removed but their stress-raising effect is partly neutralised by the compression stress which tends to close up the cracks. A similar effect may be obtained by applying at the higher temperature another substance, e.g., a glaze, with a large co-efficient of thermal expansion.

In all such cases the strength may be raised only to the figure conditioned by the internal defects.

When we turn to materials where the surface defects are relatively unimportant and the technical strength is conditioned mainly by the presence of internal hearths of excess stress we should expect to be able to increase the strength if it were possible either to hinder the growth of the cracks by introducing mechanical inclusions to change the direction of the growing cracks and permit their localisation or else to induce a re-arrangement in the structure so that it becomes oriented in a direction different from that in which in the cracks would tend to grow. Experience has confirmed that both these methods are feasible. As examples we have the use of fillers, particularly those of a fibrous nature, for strengthening plastics and the use of cold-work for strengthening metals. In the first case, the smooth, shining surface of fracture is transformed into a rough, matt one. In the second, the effect of deformation is to cause those planes on which slip would occur most easily to become oriented in a direction nearly parallel with the stress axis. The fracture is a special type, fibrous or lamellar, and the brittle properties are not usually obvious with these materials.

Another way of counteracting the effects of internal hollows in raising the stress is by carrying out a process physically analogous to heterogeneous case-hardening but here it is the internal surface of the pores and not the external surface of the material which is treated. Certain ceramic materials have been made 5 to 8 times stronger by causing a film, producing a compression stress, to form on these internal surfaces.

Thus from a mere observation of fractured surfaces Aleksandrov has been able to draw a number of important deductions and to indicate a single point of view from which the behaviour of materials of diverse character may be considered. He has introduced no new conception of fracture but he has gone a long way towards justifying those who have accepted the Griffith crack theory as a working basis in studying the problem of strength.

New Uses of Lithium

LITHIUM, according to a report of the United States War and Navy Departments, was performing the following jobs in war industry : Removes gases and impurities in copper, tin and silicon bronzes ; removes final traces of nitrogen from other gases, such as helium and argon ; is an essential compound in fluxes for welding aluminium in airplane construction and for making magnesium castings for airplane parts ; makes possible the use of lighter weight storage batteries ; in the form of lithium soaps, enables lubricants to flow freely at extremely high and at extremely low temperatures ; in air-sea rescues, lithium hydride is used to generate hydrogen for inflation of the aerial balloon which permits operation of the portable Gibson Girl radio sending set.

In addition, lithium has been mentioned for a number of possible post-war uses. The use of lithium alloys is expected to expand ; lithium hardens and toughens lead, at the same time increasing its strength. Lithium improves certain physical properties of copper castings, particularly electrical conductivity. It is a convenient grain refiner for many metals and alloys such as lead, zinc, aluminium and certain copper alloys. According to a report of Dr. H. Osborg, important developments are nearing conclusion concerning the industrial application of lithium in cast iron, carbon steels and stainless steels. The standard Edison storage battery depends on lithium salts to stabilise the amperage.

One of the most promising uses for lithium salts, according to " Chemical Industries," is in air conditioning to control moisture content of the air. Successful application of lithium compounds to lubricants and greases suggests their use in industrial soaps to improve detergency and cleansing power under adverse conditions of temperature and pressure. Additional use of lithium compounds in glass making is likely, according to the same source. Lithium carbonate is now used to increase strength and weather resistance of some types of glass. In other ceramics, lithium compounds are used to prevent " crazing," the surface cracking which sometimes occurs during cooling. Lithium compounds also are used to increase the fluidity of molten glass and to lower its melting temperature. Lithium occurs more abundantly in nature than tin, lead or zinc, a fact which is not generally known. Spodumene, an ore containing lithium, yields most of the commercial lithium products. Lepidolite and the brine of Seales Lake, California, are other sources of lithium.

The Manufacture of Seamless Steel Tubes[*]

By J. W. Jenkin, Ph.D., B.Sc., A.R.I.C.

Director of Research, Tube Investments, Ltd.

The application of seamless steel tubes in many industries has made great progress in the last twenty years. Tubular products are especially useful for conveying gases or liquids and metallurgical developments have contributed to the improvement of steels for special seamless tubes for many industries, including the oil-refining, chemical, and high-pressure steam industries; they are also being used in increased quantities for structural purposes because they combine maximum stress carrying capacity with minimum weight. Practically all the regular carbon and alloy steels may be used in the seamless process; the chromium steels containing from 1 to 30 per cent. chromium and numerous other alloyed steels containing chromium with additions of such elements as molybdenum, nickel, manganese, silicon and titanium, are included in those successfully processed. Hot rolling operations provide the bulk of seamless tubes for ordinary requirements, but, when greater accuracy, high physical properties, better surfaces, thinner walls and small diameters are required, the tubes are cold drawn as a finishing operation. The various operations in seamless steel tube manufacture are described.

Evolution of the Barrel Piercer

The introduction of rotary piercing was due to the German brothers Max and Reinhard Mannesmann just sixty years ago, and revolutionised steel tube making. The original Mannesmann Company made files and received its raw material from England, but in the 1880's tried making steel for themselves in crucible furnaces. Their long round bars were forged into shape under steam hammers and finally put through polishing mills, which is a reeling operation, in line with English practice at the time. They had much trouble with centre cracking due to the stretching action in the polishing or reeling rolls, and it is to the great credit of the two brothers that they saw in this occurrence the possibility of so governing the conditions under which the central cavity was formed that they could tackle a project that their father had experimented on 20 years previously, namely the manufacture of seamless steel tubes. Mannesmann senior had tried unsuccessfully to roll hollow-cast or drilled ingots. After two or three years of grief and pain the brothers Max and Reinhard Mannesmann recognised that the formation of a central cavity was due to the reeling effect of the roll shape, and the angle at which the rolls were set provided the forward movement. If the rolls are not at an angle, the central weakening will still occur but the billet will not travel forward. It was a great day when they decided to put a shaped plug right in the line of travel of the billet.

There are considerable variations in roll shape, within the general form

described. The angle that the tapered portion of the roll surface makes with its own axis may be anything from 6° to 20°. The essential things are the rotation of the billet as it is pulled forward by a cross rolling operation, and the weakening of the centre as an effect of the varying peripheral speed due to roll shape. The angle between these barrel-shaped rolls is generally just over 3° on either side of the horizontal, in this country. American practice (contingent on the high rate of throughput necessary) is to work at about double this angle or more, giving more rapid piercing, a much longer pierced bloom, and permitting the use of a larger plug. It is no uncommon thing in America, for instance, to convert a solid billet $3\frac{1}{4}$ in. diameter $\times$ 4 ft. 6 in. long into a pierced bloom $3\frac{1}{2}$ in. outside diameter $\times$ $\frac{5}{16}$ in. thick $\times$ 14 ft. long in one operation on this rotary piercing mill.

Frequently billets are put through two piercing mills of similar design, one after the other, or through the same mill twice, the first operation serving to pierce to a relatively thick wall, and the second to expand the hole and elongate the bloom. This is said to improve the concentricity, since any eccentricity produced in the first operation results in a temperature difference between the thick and thin sections, which favourably influences the displacement in the second piercing mill. Piercing to a thinner wall as in the U.S.A. has the merit that it does the maximum work when the steel is best able to stand it, i.e., when it is hottest. Piercing, however, is only the first stage of a two-stage job, and many factors influence a decision as to how to do the elongating. The best

combination in this two-stage process will depend amongst other things on the size and shape of the order book. The pierced bloom is, of course, a rough thick-walled article which is of practically no use as it is; it emerges at anything from 1100–1200° C. so still has plenty of residual heat for subsequent elongation.

Disc Piercer

One of the Mannesmann engineers R. C. Stiefel, carried the idea of cross rolling between rolls of varying peripheral speed to the use of two mushroom-shaped discs on parallel but offset axes. In this method one has the same principle of causing a billet to enter a tapering space between two rolls rotating in the same sense, so the billet will spin in the reverse sense.

The Stiefel mill is very fast and causes severer twist on the steel than the Mannesmann mill; in an extreme experimental case, with a $3\frac{1}{4}$ in. diameter billet on which a longitudinal groove had been cut, it was found that after going through the disc piercer over a $1\frac{1}{4}$ in. plug the remains of the groove showed that the outside surface had made one complete twist in 13 in. The time occupied in piercing depends on the billet length and may vary from a few seconds for short small billets through a Stiefel disc mill to about a minute or more through the largest Mannesmann barrel mill. Jets of water run on to the rolls all the time.

Cone Piercer

Another variation practised in America may be regarded as intermediate between the Mannesmann barrel mill and the Stiefel disc mill: this is the 60° cone mill, in which, as

Fig. 9.—Stiefel piercing : (i) billet at 1250° C. being centre punched by end-wise pressure.

"Tannhäuser" the pilgrims approached the shrine by taking three steps forward and two back, and the pilgrims' chorus is called the " Pilgerchor." The pilger mill works on the pilgrim principle of causing the bloom to pass through the rolls step by step, making a certain amount of real progress at each stroke.

In this step rolling process, the rolls, in contradistinction to bar rolling, work against the job, forcing it away from the mill whenever they can ; but the important thing is that the groove around the roll is not of uniform depth and width, as when rolls are pulling a bar forward : for a part of the periphery, the groove is tapered from something larger than the bloom size down to the outside diameter of the tube to be rolled. This occupies about half the circumference of the roll; elsewhere the roll profile leaves a com-

the name suggests, conical rolls are set at that angle. The same type of mill is used to expand very large diameter tubes that have already been pierced. In such a mill it is common to expand a tube about 16 in. o.d. $\times \frac{1}{4}$ in. thick to about 24 in. o.d. $\times \frac{5}{16}$ in. thick, the length remaining about the same.

Pilger Mill

The business of elongating the pierced bloom may be carried out in several ways, all of them complicated by the fact that there is a hole in the middle, which has to be filled somehow to avoid collapse. One method, developed in Germany by Mannesmann and extensively used there and here, is the pilger mill, a step rolling process that like rotary piercing is not easy to describe. Musicians will remember that in Wagner's opera

Fig. 11.—Stiefel piercing : (iii) billet spinning into mill, rear view.

Fig. 10.—Stiefel piercing : (ii) centre-punched billet falls into trough ready for entry into space between rotating discs.

plete gap. The exact form of the tapered portion is too complicated a matter to describe here, but when top and bottom rolls are synchronised, the effect is that the gap between the working portions opens and then gradually closes with each revolution. The pierced bloom is carried on a mandrel bar into this gap, and pressure is applied to the back of both bloom and mandrel. The bar inside is long enough for its forward end to serve as an anvil on to which the rolls squeeze the bloom step by step. When the wide ends of the grooves in the rolls are opposite each other, the gap is big enough for the bloom to enter ; continued rotation of the rolls against the bloom then squeezes the steel back along the bar until the thickness of the material corresponds to the annular space between the bar and the rolls at the smallest end of their groove. At

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Fig: 12.—Stiefel piercing : (iv) pierced bloom emerging from mill.

this smallest end the groove is parallel for a substantial part of the roll circumference so as to iron out inequalities of thickness.

It will be clear from the roll profile that the gap then suddenly widens again, forward goes the tube, and with each revolution of the rolls another bite of the pierced bloom is taken and rolled out into a tube. If the partly pilgered tube is withdrawn, the shape of the cone between bloom and tube will thus be a projection of the groove that varies around the roll. Eventually the end of the pierced bloom is reached, and one either has to leave a bell end on it, or employ some means for rolling right out, such as by having a hot ring as a distance-piece between the back end of the pierced bloom and the pushing mechanism.

An important feature, since there has to be some flare at the sides of

the roll groove, is that the tube is rotated on the bar after each stroke. The amount of rotation can be varied at will, and in practice is generally of the order of 90°.

This is therefore not a forging job in the hammering sense : rather is it a kneading operation differing little from bar or slab rolling. The fact that there is an audible knock as the bloom strikes the rolls, especially in the first few strokes, should not deceive us into calling it hammering. As the kneading takes place, the mandrel is pushed back against the pressure of an air-loaded recoil cylinder. When the gap in the rolls comes round, the bloom on the mandrel bar is thrust forward, and at the same time, by means of a screw and nut motion, the bloom is given a quarter turn.
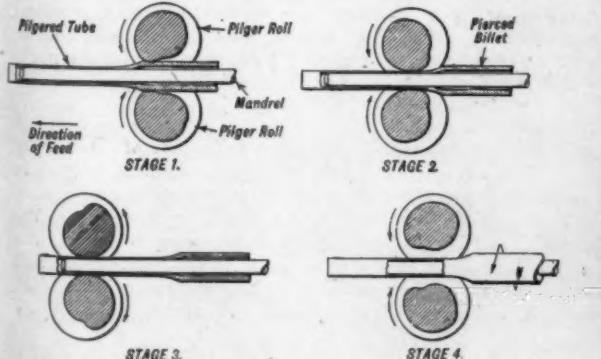
The revolution of the pilger rolls may be anything from 50 to 300 per minute, according to size of mill and of the tube to be made. There is of course no limit as to length, in the sense that one can go on pilgering as long as there is some pierced bloom to push into the rolls. By way of demonstration, one company once pilgered a tube $10\frac{1}{4}$ in. outside diameter $\times$ $\frac{3}{16}$ in. thick by no less than 135 ft. 8 in. long, or thereabouts, but one couldn't do anything, not even turn a corner, with a thing of that length. There are inevitably a few ragged inches at the ends, especially the starting end, so naturally one rolls the maximum length to cut down scrap, consistent with handling facilities and what is to be done with the tube afterwards.

The size range of the pilger process is illustrated by the following typical dimensions. The smallest tube pilgered is generally 2 in. o.d., though $1\frac{7}{8}$ in. and even $1\frac{3}{4}$ in. are practicable, but at those diameters a thick tube would mean that the mandrel bar gets too hot during rolling. A common thickness in these small diameters is 8 gauge (0·160 in.), but both 12 gauge (0·104 in.) and 4 gauge (0·232 in.) offer no difficulty. At the other end of the scale tubes are pilgered up to 16 in. and 18 in. outside diameter, in thicknesses down to $\frac{3}{8}$ in. At 13 in. o.d., for instance, a thickness of 1 in. is quite practicable ; so, for that matter, is 6 in. $\times$ $1\frac{1}{2}$ in. thick. The famous Iraq pipe line included 320 miles pilgered in Birmingham to $12\frac{3}{4}$ in. o.d. $\times$ 0·330 in. thick $\times$ 90 ft. long as rolled (cut in half for transport) from cast round ingots $18\frac{1}{4}$ in. diameter $\times$ 5 ft. 3 in. long and thus getting on for 2 tons in weight. For this purpose the billets were rolled continuously down the sloping hearth of an oil-fired furnace

Fig. 14.—Close-up view of the groove in a pilger roll.

Fig. 13.—Diagram illustrating step-rolling in a pilger mill.

Pilgered Tube — Pilger Roll — Pierced Billet

Direction of Feed — Mandrel — Pilger Roll

STAGE 1.   STAGE 2   STAGE 3.   STAGE 4.

(which is now fired by pulverised pitch) 75 ft. long and some 10 ft. wide. The last 3 or 4 feet is at a steeper slope, down which the billets roll to knock open hanging water-cooled doors, consisting in fact of flattened steel tubes.

The pilger process has the advantage over the push bench that there is less

Plug Rolling

How else can this elongating be done ? While push benches and pilger mills are the methods in predominant use in this country, rotary piercing is often followed (particularly in America) by what is called an automatic mill, in which the bloom is elongated by pass-

some risk of scoring of the bore, but the output is enormous, requiring extensive space for handling and cooling facilities. Such mills produce tubes from, say, 2¼ in. to 16 in. outside diameter in lengths only governed by the mechanical problems of supporting a plug at the end of a long bar. After

Fig. 15.—Diagram illustrating the Diescher elongator.
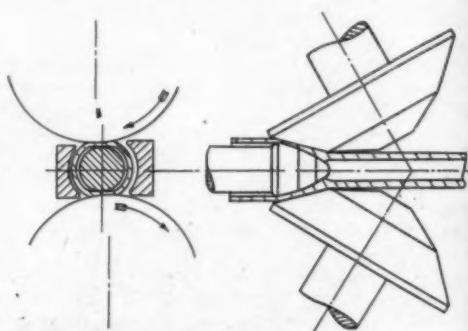
Fig. 16.—Diagram illustrating the rotary expanding mill.

Fig. 17.—Showing some typical tubular forgings.

Fig. 18.—Showing forgings of flanged tube.

ing it through a two-high mill consisting of grooved rolls that work *with* the job as in a reversing bar mill, unlike the pilger rolls working against the bloom. The bloom is rotated 90° between passes. The upper roll can

limitation of length and it can make very thick walled tubes, but this pilgrims' progress is relatively slow. It is common for one rotary piercing mill to feed two pilger mills. Very broadly, the pierced bloom is double the length of the original billet, and the pilgered tube is some six times the length of the pierced bloom, so the total extension from billet to tube will be twelve times or more.

be raised quickly to open the pass. The bore is maintained by inserting in the path of the bloom in the roll gap a plug on the end of a long bar, something the shape of an artillery shell, but with a blunt nose. Stripper rolls encircling the bar that supports the plug are located behind the main rolls, and serve to bring the tube back to the entry side for a second pass. The plug being stationary, there is always

plug rolling the tube is passed through a reeler to round it up and burnish both surfaces against respectively a plug inside and stationary guides above and below the space between rolls of the Mannesmann type.

Diescher Mill

Attempts have been successfully made, particularly in America, to apply the cross-rolling principle of the primary stage of piercing to the secondary stage of elongating the pierced bloom. In the Diescher mill, for instance, a long bloom, that is, one pierced in Mannesmann barrel rolls, set at a greater angle than is common in this country and over a larger plug, is given a second pass through similar rolls after having a long bar loosely inserted in it. Support above and below is provided by large discs some 3 ft. in diameter and about 2 in. thick, the periphery of which is of such a contour as to assist the forward motion of the bloom. Some slip on these discs is, of course, inevitable, and it requires good steel to stand up to the punishment of the surface. The resulting tube has an enviable reputation for concentricity.

Assel Mill

Another application of the cross-rolling principle is the mill designed in America by Assel, more particularly for the production of thick tubes. His elongator consists of three barrel-shaped rolls of appropriate contour and setting, and the bloom is stretched by passing it through the space

between them very much as in piercing but with a bar loosely inserted in the previously pierced hole. The mill is in successful operation in America on the manufacture of tubes for bearings in both carburising and direct hardening steels, and a similar unit was installed in Germany a year or two before the war. Both Diescher and Assel, it will be observed, employ a bar to support the bore, travelling with the tube, so this bar has to be withdrawn by gripping the bar while the tube passes on.

Foren Mill

This rolling on a bar has been applied in one American mill to a non-rotating method. In the Foren mill the pierced bloom, again relatively long and thin, passes with its inserted bar through a train of roll stands, each roll groove being smaller than the one in the previous stand. Speeds increase from stand to stand to keep pace with the elongation of the tube, and the axes of alternate pairs of rolls are at 90° to the others. In this way both diameter and thickness are reduced. Rolling on a bar in this fashion avoids the twist and surface slip of rotary processes, the plug scoring of the automatic mill, the length limitations of the push bench and the low output of the pilger mill.

Fig. 19.—Typical continuous reducing mill for hot sinking tubes without internal support.

To date there is only one such mill, but it seems a likely line of development for smaller tube sizes. The upper limit of size would probably be set by the problems of handling heavy mandrels and their cooling effect on the tube.

Reducing Mill

The idea of passing a tube through a a succession of rolls, the axes of alternate pairs of rolls being at 90° to the others, has been common enough for rolling *without* internal support. This is the so-called continuous reducing mill, which is used for diameter reductions only, subsequent to the pilger mill, push bench, or other elongating process. From these latter processes the tube has so fallen in temperature that re-heating at 1,000° C. or so is necessary for hot reducing.

The tube is conveyed to the first pair of rolls, and once it is gripped by them it is rolled on to the next stand, where it suffers a further reduction in outside diameter. This means that successive pairs of rolls must not only have smaller grooves to effect that reduction, but must also travel at a higher peripheral speed, since the tube lengthens as its diameter is reduced. Thus there arises the need for a very nice balance between the amount of diameter reduction at each stand and the speed of the rolls in the stands on either side, to avoid the danger of undue tension between stands or even compression. In other words, one needs a proper relation between sink and stretch.

In the absence of tension, thickening of the tube will occur; tension is in fact absent when the tube is only held by the first pair of rolls, and this is bound to occur when the tube enters the mill and when the other end leaves it. So if thickening of the ends for the length between the first two and last two roll stands is detrimental, then undue tension between rolls must be avoided.

Again, two rolls can only grip the tube for the major part of the circumference, not for the whole of it, and only a part of the groove at any one instant can be travelling at the same peripheral speed as the tube itself; there must be slip somewhere. The effect of this is that the tube tends to thicken non-uniformly around its circumference.

When successive pairs of rolls are at 90° to each other, thickening tends to be greater in regions around the circumference about north, south, east and west. So while the tube will be round on the outside, the bore may depart slightly from the round in the direction of becoming square. This can be overcome by having four rolls bearing on the outside of the tube at each stand instead of two, a result achieved in what is called the " quarto " mill at the expense of increased maintenance costs. To the same end, the angles between the roll axes in different stands may be other than 90°.

For many practical purposes the variation in thickness that may occur around the circumference or from end to end does not matter; in any case if the tubes are finally cold drawn, these variations are eliminated. A reducing mill is only used for sizes too small for direct rolling by the other processes described, and to save cold work by providing a smaller starting size, down to $1\frac{1}{16}$ in. outside diameter.

Hot Drawing

Another hot method of reducing the outside diameter without internal support is hot drawing, in which the heated tube, pointed at one end, is pulled through a die by engagement into a travelling carriage that can be hooked into an endless chain. The rate of pulling is rapid enough, but the practicable reduction per pass is relatively small. While the change in wall thickness is uniform, the output is relatively low compared with a reducing mill. The variation in strength of steels at high temperatures means that unless the tube is uniformly heated it will stretch irregularly, and even pull into two. In spite of its limitations, hot drawing is still practised, particularly at a well-known works in Scotland.

" Forging "

Before leaving the subject of hot work, it would be as well to refer briefly to some methods of altering the

relations between diameter, thickness, and length by means of what are called forging processes, carried out on portions of the hot finished tube locally heated for the purpose. For instance the heated ends may be expanded by the insertion of a plug or mandrel, as in making inserted joints for pipe lines. They may be tapered by pushing them into dies that are caused to give a rapid succession of blows in a rotary swaging machine. They may be flanged, upset (internally or externally), reduced, or expanded, in appropriately shaped tools in an Ajax machine; oil firing is usual for heating the tube ends, and more than one heat may be necessary.

One firm in particular has developed this to a fine art with the consequent production of a bewildering variety of shapes to the great satisfaction of the user in saving elaborate machining, to say nothing of providing an article in which the grain flow of the steel follows the optimum path. Similarly, the ends of steel tubes may be wholly or partially closed to form the familiar ends of the conventional shape of gas cylinders, adapted to take a valve or plug at one or both ends; this is done in so-called necking hammers containing two half tools that give a rapid succession of blows to the rotating hot end of the tube.

Assistance to such a job may be provided by pushing the tube end into a succession of cups of proper shape, the business end of the tube being, of course, hot. The great art is to choose the proper tool shape to ensure sufficient thickening to take the required thread in the neck without gathering up so much metal that the bore crinkles badly at the small end. For complete closing the heated end may be spun hot and finally sealed. Other hot operations, of which space precludes detailed description, include hot bending, filled with sand or empty, requiring considerable skill and craftsmanship.

All the processes so far described give what is called the hot finished tube. The term " hot rolled " is often applied, but is really a misnomer, since, as has been shown, the tube may be pushed, kneaded, pulled, or even squirted. As is inevitable with hot processes, it is impracticable to work to fine dimensional limits, and the surface is rough and covered with mill scale. For many purposes such tubes are eminently satisfactory; indeed, the hot finished tube accounts for the greatest tonnage, as distinct from feetage, of the world's output. Since the finishing temperature is generally of the order of 900° C., the tube is metallurgically to all intents and purposes in the normalised condition. Air hardening steels will of course harden as the tube cools, but except in the simplest cases are subsequently heat treated.   *To be continued.*

Reviews of Current Literature

Aluminium Alloy Extruded Sections
Notes on Design and Manufacturing Tolerances

The value of the extrusion process as a method of producing aluminium-alloy sections in an almost endless variety of shapes is now so well-known as hardly to need emphasis. But whether light alloy extrusions have always been used in the past in the most efficient way is another matter, and the aim of this brochure, which has been compiled by the Technical Committee of the Wrought Light Alloys Association and published for that body by the Aluminium Development Association from which copies are obtainable, is to provide design staffs with the necessary information on the design of extruded sections to make for maximum efficiency.

It is pointed out that the most readily extruded shapes are round bars and simple shapes, such as squares, hexagons and rectangles, which approach symmetry. Where more complicated shapes are required, it should be borne in mind that the ideal to be aimed at is a balanced flow of metal through the die.

An important point stressed is the fact that sharp corners should be avoided since a small radius on corners—as little as thirty or forty thousands of an inch it may be—greatly increases ease of extrusion and also the life of the die.

The application of these principles is seen schematically in a series of diagrams illustrating symmetrical sections, box sections and deep channels, angles and tees with sharp corners, wedge sections, abrupt changes of thickness, sections with long, thin arms, bulb-ended sections, thin, flat sections and channels.

Comprehensive data on manufacturing tolerances are given in tables covering round bars, hexagonal bars, overall widths for regular sections, thickness for regular sections, open ends for right-angled channels, I beams, H sections, etc. Also included is a brief summary of the mechanical properties of typical aluminium alloys quoted, by permission, from B.S. 1161, 1944, "Aluminium Alloy Sections."

Copies of this publication may be obtained on application to Aluminium Development Association, Union Chambers, 63, Temple Row, Birmingham, 2.

Spectrographic Analysis

FOR some years past the British Non-Ferrous Metals Research Association Sub-Committee on Metallurgical Application of the Spectrograph has operated through various panels covering different aspects of the work. At present four panels are operating, dealing with photographic, analysis of aluminium alloys, analysis of lead and lead alloys, and general research. In addition to guiding the Association's own spectrographic researches, the individual members of the panels have provided results obtained in their own laboratories. As a result of this work a considerable number of reports have been distributed to members of the Association. Efforts have been made to reduce the effect of variables that interfere with the reproducibility of the results obtained.

Based on the many reports submitted a selection of thirteen papers is published in the present volume. The papers comprise two on the processing and calibration of the photographic plate ; four on analysis of aluminium and aluminium alloys ; one on zinc alloys ; two on copper alloys ; and one on platinum. Six of the papers are from members of the Association's staff, three from member companies, and one from a Government department, while the remaining three are reports from panels of the Sub-Committee. All are of a practical character and contain useful recommendations on procedure ; they cover a wide range in the application of the spectrograph to non-ferrous metals and will be of special interest to those who use the spectrograph in this field.

Edited by D. M. Smith. Royal 8vo. 162 pp. 1945. Published by British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1.

A Metallurgical Study of German Aircraft Engine and Airframe Parts

This report constitutes a summary of further data, resulting from the metallurgical examination of German aircraft engine and airframe parts by the Aero-Components Sub-Committee of the Technical Advisory Committee of the Special Alloy Steel Committee formed for that purpose.

The types examined represent a comprehensive range of various types of German aircraft which have fallen into the hands of the R.A.F. from 1942 onwards.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts have been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions, due to our blockade, on German procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations. The Sub-Committee responsible for these investigations and for this report comprise ; Mr. S. Barraclough, United Steel Companies, Ltd.; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd. ; Mr. H. H. Burton, the English Steel Corporation, Ltd. ; Mr. W. J. Dawson, (Chairman), Hadfields, Ltd. ; Dr. R. Genders, M.B.E., S.T.A.M., Ministry of Supply ; Mr. H. J. Hipkins, Royal Aircraft Establishment: Mr. N. H. Mason R.A.E., Farnborough; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd. ; Mr. L. Rotherham, Thos. Firth and John Brown, Ltd. ; Dr. H. Sutton, Ministry of Aircraft Production ; Miss M. K. Walshaw, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out as a continuation of the data already published.* It has been carried out meticulously. Naturally in this Report no comparisons are made with corresponding parts in British and American Aircraft, neither are certain aspects which our investigations have shown to be open to criticism emphasised.

Section VIII.—Gears

SINCE the publication early in 1943 of the first report summarising the results of the metallurgical examination of 17 gear wheels, a further 21 have been examined and these form the subject of the present summary. As in the first summary observations have been confined to the purely metallurgical aspects of the steel as regards quality and structure.

All the relevant data have been extracted as before from the individual reports, and are set out for ease of comparison in tabular form. In the tables the same system of grouping according to chemical composition has been followed but in the present case, the steels fall into three groups.

All the gears examined were of German origin and it will be noticed that in some cases, particularly in the later examples examined, investigations have not been made as extensively as before. This is logical occurrence as a number of aspects investigated with the earliest examples have ceased to have any particular significance.

The approximate sizes have again been included in the tables to convey a general idea of the proportions of the gears examined.

Appearance and Finish

All the gears examined showed the same high standard of surface finish as those of German origin previously reported and no special comment other than this is called for.

Composition

All the gears examined were found to be made from case-hardening alloy steels and the three groups in which they have been classified in the tables are :—

(a) 2% Cr 2% Ni Mo with or without vanadium covering 12 gears.

(b) 1% Cr 2% Mo covering 5 gears.

(c) 1% Mn 1¼% Cr without or with traces only of Molybdenum. Covering 4 gears.

In considering the compositions by groups, it will be noted that there were wide variations in individual elements in each group to such an extent as to suggest that further sub-division of the groups should have been made and this is in distinct contrast with the results given in the summary of the first series examined, where with one exception the carbon contained was 0·16/0·18%. The results are discussed below.

Carbon. In the twelve examples of 2/2 Cr Ni steel the carbon content varied between 0·14 and 0·25% and there was no indication of the value intended beyond noting that three examples contained 0·19% carbon which was close to the average for the series. These variations were not reflected in the core hardness values.

The 1% Cr Mo group also showed a wide range of carbon content, i.e., 0·16 to 0·24%. The individual figures were not directly related to core hardness although the two highest were associated with the two highest in carbon.

In the four examples in the 1% Mn Cr group it seemed that a higher carbon range was intended, the figures falling in the range 0·20 to 0·25%. The tensile test results on the duplicate gear items 180 and 208 are in line with the difference in carbon content of these two.

Silicon. The range covered by steels of all three groups was 0·12 to 0·38%, over half of them being between 0·25 and 0·30%. In the previous summary it was noted that the latter also applied but that the scatter was narrower, i.e., between 0·18 and 0·35%. Of

the three lowest in silicon items 120 and 194(b) were clean and the silicon content does not therefore reflect unsatisfactory melting practice. It may do so however, in the case of item 189(a) with 0·13% silicon, as the steel was rather dirty in character.

Manganese. In the 2/2 Cr Ni group, manganese varied between 0·38 and 0·55%, the general range being 0·47 to 0·55% suggesting ·50% as the target composition.

The average value of manganese in the five steels of the 1% Cr Mo group was 0·86% as compared to 0·89% in the four of the first summary, and the range was rather wider at 0·72/1·0%

as compared to 0·81/1·02%.

The manganese content of the 1% Mn Cr group was notably higher than that of the Cr Mo, the range being 1·16 to 1·34%.

Sulphur and Phosphorus. On the whole the steels had a high standard of purity of the order which one would expect from basic arc electric steel. There were certain exceptions to the general standard, for example, items 189(a) and 192(b) contained 0·021% and 0·026% sulphur respectively and it is interesting to note that both are unsatisfactory as regards cleanness.

The phosphorus content was, as expected, generally higher than the

sulphur and item 192(b) contained 0·022%. Two others were noted with 0·018%.

Nickel and Copper. As a contaminant element, nickel was determined in all cases, but copper in only a few. Both show that the raw materials used were contaminated with these elements to a similar degree to what is found in British practice, nickel being present up to 0·39%.

Vanadium. The presence of vanadium was found in only one steel out of the 13 examined, the proportion in the previous summary being six out of fifteen. The significance of this was not clear but it pointed towards a

TABLE I. DESCRIPTION.

Item No.	Ref. to Similar Items	Machine and Engine	Type of Gear	Type Steel	Description
120	See 183 below	Junkers Juno 211/F 1	Camshaft Pinion	2/2 Cr/Ni Mo	Spur Pinion with four attachment holes in the web.
149		B.M.W. 801A/1 (Dornier 217E/1)	Valve Cam Wheel	1½ Cr/1½ Ni/Mo	Spur gear flanged on one side. Flange recessed to form lands which rise in four places to form lugs. All surfaces smooth ground and coated all over except tooth faces with a greenish lacquer.
189(a)	See 189(c) below	Junkers Jumo 211 J Junkers JU 88	Primary Gears Narrow Spur Wheel	2Cr/1½ Ni Mo	Spur gear with 16 attachment holes in web. Emery finish all over except teeth and inside of hub. Teeth fine machined on tips and fine ground elsewhere.
189(b)	See 189(c) below		Primary Gears Wide Spur Wheel	1½Cr/2 Ni Mo	Spur gear with 16 attachment holes in web. Emery finish one side and emery + ground finish other side. Teeth fine machined on tips but otherwise and also hub interior fine ground.
190(a)		Junkers Jumo 211 J (Junkers JU 88)	Secondary 2-speed gears. Gear shaft	2/2 Cr Ni Mo	Spur gear integral with shaft.
190(b)			Secondary 2-speed gears. Pinion	2/2 Cr Ni Mo	Spur gear with hub on one side fitted with a nitrided collar and sleeve, and splined in the bore.
192(a)	See 192(b) below	B.M.W. 801/A	Primary drive between crankshaft supercharger larger outer gear.	1½ Cr/2½ Ni Mo	Spur gear run with 10 internal lugs. Teeth and lugs smooth ground. Grit blasted and varnished dull green elsewhere.
193		B.M.W. 801/A	Main gear box spindle. Driving Impeller shaft Pinion	2/2 Cr Ni Mo	Spur gear with 8 lightening holes in web. Short hub on one side but longer and slender hub on opposite side splined internally to fit on the shaft. Web slightly convex on shaft side.
194(a)	See 194(b) below	B.M.W. 801/A	Supercharger drive. High Speed Clutch Pinion	2/2 Cr Ni Mo	Smooth machined but no special effort appears to have been made to remove all the machining marks on the teeth. Gear fixed to body by welding.
196(a)		B.M.W. 801	Secondary gear box Spindle. Fixed Pinion	2/2 Cr Ni Mo	Spur gear integral with hollow shaft. Web has 6 lightening holes. Gear portion lacquered all over except teeth.
196(b)			Secondary gear box Spindle Loose Pinion	2/2 Cr Ni Mo	Spur gear with solid flange splined in the bore and lacquered all over except teeth and splines.
199		B.M.W. 801/A	Impeller shaft	2/2 Cr Ni Mo	Gear integral with a hollow shaft which may have been given a phosphate treatment before being varnished a dull green colour.
183	See 120 above	Junkers Jumo 211J (Junkers JU 88D)	Camshaft Pinion	1% Cr Mo	Spur pinion with four attachment holes in web.
188			Bevel Pinion attached to clutch driving shaft	1% Cr Mo	Bevel pinion splined in bore with hub on one side to take a roller race.
189(c)	See 189(a) 189(b) above	Junkers Jumo 211 J (Junkers JU 88)	Primary gears Internal gear	1% Cr Mo	Gear wheel run with teeth cut internally and flanged at one edge outside. Flange dulled and tapped for attachment to item 189(b) above. Tips of teeth fine machined. Teeth fine ground. Fine emery finish elsewhere.
192(b)	See 192(a) above	B.M.W. 801/A	Primary drive between crankshaft supercharger. Small inner gear	1% Cr Mo	Spur gear integral with plate on which are 10 double lugs to form a spring drive with the outer gear (192a). All wearing parts smoothly ground but elsewhere grit blasted before varnishing dull green.
194(b)	See 194(a) above	B.M.W. 801/A	Supercharger drive low speed clutch pinion	1% Cr Mo	Pinion with web recessed on one side to form hub. Smooth machined but no special effort appears to have been made to remove all the machining marks on the teeth.
180	See Item 1 See 208 below	Junkers Jumo 211 J (Junkers JU 88 D)	Reduction gear fitted to crankshaft	1% Cr	Deeply recessed both sides to form hub. Bore splined in centre. Teeth well radiused.
208	Identical with 180 above	Junkers Jumo 211 F (Junkers JU 88 A)		1% Cr (0·07 Mo)	As 180 above.
289(a)	See Item 19(c)	Daimler Benz 605 (Heinkel 177)	Spring Drive Outer Gear	1% Cr (0·07 Mo)	Spur gear with narrow internal flange. Flange bored and slotted to accommodate springs and fittings. Similar to Item 19 but evidently designed to carry heavier loads.
289(b)	See Item 19(b)		Spring drive. Pinion.	1% Cr (0·06 Mo)	The pinion is an integral part of a hollow shaft flanged at one end and with clutch dogs cut at the other.

trend in the direction of economy in alloy or possibly shortage of vanadium bearing raw materials.

Chromium and Nickel. As has been noted earlier in this summary, the divergence from the standard 2/2 composition was wide enough to suggest the possibility of alternative compositions being used. Thus the chromium content in this group varied between 1·57 and 2·09% and the nickel between 1·56 and 2·26%, but the individual low figures were not associated with departures from the standard values for the other constituents. If significance is to be attached to this it would mean some relaxation in the rigidity of the chemical specification.

The Cr content of the five steels in the Cr Mo group varied between 0·87 and 1·13% compared to 1·04 and 1·22% in the previous summary of four steels.

In the Mn Cr group the Chromium content is higher—and it was thought deliberately so—at 1·23 to 1·34%.

Molybdenum. In the 2/2 Cr Ni group the Mo varied between 0·14 and 0·29%, whereas in the previous summary the steels (with one exception at 0·08%) were more consistent, with a range of 0·24 to 0·35%.

The results for the 1% Cr Mo steels also by comparison were inconsistent and generally lower in Mo content.

It was considered that the small amounts of Mo noted in the Mn Cr group were not deliberately added except in the sense that they were probably present in the scrap used in the furnace charge.

Considering the analyses of the steels as a whole they contrast in a marked manner with those of the earlier report as regards lack of uniformity of individual elements. On the one hand this suggests relaxation in control of compositions or alternatively, that selection of steels by analysis according to the duty of a particular gear is practised. In either case the effect would be that of reducing restriction of output by absorption of "off casts" into production.

The introduction of 1% Mn 1¼% Cr steel was noted as not having been met in those examined in the first summary, and an indication of a

TABLE II. COMPOSITION AND HARDNESS.

Item No.	Approximate Size	No. of Teeth	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Position	Depth In.	Case	Core
120	4 in. o.d. × 1½ in. bore × ⅜ in. wide.	32	0·22	0·15	0·51	0·014	0·015	2·02	2·00	0·28			Teeth only		821–841	442–459
149	10 in. o.d. × 8 in. bore × ⅞ in. wide tooth face × 2⅜ in. wide overall.	90	0·25	0·28	0·38	0·009	0·010	1·56	1·84	0·34	0·14	0·12	All over except in the recess behind the teeth	0·04–0·06	752–792	434–496
189(a)	7 in. o.d. × 2¼ in. bore × 11/16 in. wide tooth face × ⅞ in. wide overall.	88	0·16	0·13	0·55	0·021	0·013	1·56	2·17	0·19	Nil	0·01	Teeth only	Variable up to 0·045 max.	752–798	421
189(b)	7⅞ in. o.d. × 2¼ in. bore × 1⅜ in. tooth face.	93	0·19	0·25	0·51	0·011	0·009	1·94	1·57	0·20	Nil	0·14	Teeth only	Uniform 0·025	774–798	440
190(a)	1⅞ in. o.d. × ½ in. bore × 1⅜ in. tooth face × 7 in. wide overall	16	0·14	0·20	0·53	0·013	0·012	1·76	2·07	0·22			Teeth only	0·020–0·025	732–770	374–389
190(b)	1⅞ in. o.d. × ⅞ in. bore × ⅞ in. tooth face × 1⅜ in. wide overall	18	0·14	0·30	0·49	0·010	0·011	1·77	2·05	0·14			Teeth only	0·020–0·025	788–802	413–416
192(a)	10 in. o.d. × 1 in. wide.	76	0·19	0·30	0·39	0·011	0·012	2·26	1·60	0·29	Nil		Teeth and lugs	Up to 0·015	689–726	272
193		67	0·18	0·25	0·47	0·008	0·009	1·78	2·09	0·18			Teeth and inside and outside of splined hub	0·035–0·040	736–784	436–442
194(a)	3 in. o.d. × 2 in bore × 1 in. tooth face × 1⅜ in. wide overall.	22	0·22	0·30	0·53	0·010	0·009	1·74	2·08	0·15	Nil		Teeth only	0·026	763	398
196(a)	4¼ in. o.d. × ⅞ in bore × 1 in. tooth face × 9⅜ in. long overall.	30	0·19	0·25	0·50	0·011	0·007	1·78	2·04	0·16		0·06	Teeth and splined end of shaft	0·020–0·030	687–774	410–464
196(b)	3½ in. o.d. × 1 in. bore × ⅝ in. tooth face × 1¼ in. overall	25	0·20	0·26	0·52	0·010	0·008	1·80	2·05	0·15		0·06	Teeth and bore	0·020–0·030	697–712	414–447
199	4½ in. o.d. × 1⅛ in. bore × ⅞ in. tooth face × 11 in. overall length	(32?)	0·15	0·31	0·47	0·010	0·011	2·08	1·91	0·25			Teeth and parts of shaft	0·030	752–782	387–450
183	4 in. o.d. × 1½ in. bore × ⅜ in. wide.	32	0·21		0·97			9·05	0·87	0·14			Teeth only		807–826	377–385
188	3⅛ in. o.d. × 1¼ in. bore × 2⅛ in. wide × 1⅜ in. tooth face.	11	0·16	0·24	0·80	0·008	0·011	0·23	1·03	0·12	Nil	0·08	Teeth only	0·035	752–824	336
189(c)	6⅞ in. o.d. × 5⅜ in. bore × 1¼ in. wide.	94	0·16		0·82	0·013	0·016	0·06	0·95	0·20	Nil		Teeth only	0·015	Tip 833 Sides 511–575	361
192(b)	9 in. o.d. × 4½ in. o.d. teeth × ⅝ in. tooth face × 1⅝ in. wide overall.	40	0·16	0·34	0·72	0·026	0·022	0·30	1·13	0·20	Nil		Teeth and lugs	0·040	689–726	303
194(b)	3⅜ in. o.d. × ⅞ in. tooth face × 1⅜ in. wide overall × 1⅜ in. bore	27	0·24	0·12	1·00	0·010	0·010	0·39	1·07	0·23	Nil		Teeth only	0·026	705	396
180	7½ in. o.d. × 3⅜ in. bore × 2⅜ in. tooth face × 3 in wide overall	36	0·20	0·30	1·28	0·008	0·015	0·01	1·31	Tr.	Nil		Teeth only	0·05	752 782	Approx. 300
288	As Item 180 above.	36	0·25	0·38	1·16	0·014	0·014	0·55	1·23	0·07	Nil		Teeth only		734–762	Outside 450 Inside 350
288(a)		58	0·23	0·27	1·16	0·004	0·018	0·24	1·29	0·07	Nil		Teeth only		803–813	360–368
288(b)		(18)	0·22	0·25	1·34	0·004	0·018	0·18	1·34	0·06	Nil		Dogs, teeth and most of outer surface		813–824	406–415

TABLE III. GRAIN SIZE, MECHANICAL PROPERTIES AND MACROSTRUCTURE.

Item No.	McQuaid Ehn Grain Size	Mechanical Properties						Macrostructure
		Position	0·2% Y.P. tons/sq. in.	U.T.S. tons/sq. in.	El. %	R. of A. %	Izod ft. lbs.	
120	5–6	—	—	—	—	—	—	Lines of flow suggest upset forging with the probability that the gears were forged in multiples. A considerable amount has been removed by machining.
149	—	—	—	—	—	—	—	Made as an upset ring forging but a considerable amount removed by machining.
189(a)	2–5	—	—	—	—	—	—	Made as an upset forging.
189(b)	2–5 (with 1)	—	—	—	—	—	—	Made as an upset forging.
190(a)	6	—	—	—	—	—	—	Roughly forged to profile probably by upsetting.
190(b)	6	—	—	—	—	—	—	Made as an upset forging.
192(a)	7 (with 5)	—	—	—	—	—	—	Made as an upset ring forging.
193	6	—	—	—	—	—	—	Made as an upset forging but a considerable amount removed by machining.
194(a)	6–7 (with 5)	—	—	—	—	—	—	Made as an upset forging and fitted to housing sleeve by welding.
196(a)	—	—	—	—	—	—	—	Made as an upset forging.
196(b)	—	—	—	—	—	—	—	Made as an upset forging.
199	—	—	—	—	—	—	—	Not upset but made by drawing down in forging from gear diameter.
183	3–5	—	—	—	—	—	—	Made as an upset forging but apparently in single blanks. (See Item 120.)
188	7	—	—	—	—	—	—	Made as an upset forging.
189(c)	4–5 (with 3)	—	—	—	—	—	—	Made as an upset forging.
192(b)	3–5	Tangental from plate portion	—	62·4	21	—	—	Made as an upset forging.
194(b)	5 and 6	—	—	—	—	—	—	Made as an upset forging.
180	6–2	Parallel to bore	—	65·4	18	30·5	20	Made as an upset forging.
208	—	—	—	79·5	14·1	46·0	14	
289(a)	—	—	—	—	—	—	—	Made as an upset forging and a considerable amount removed internally by machining.
289(b)	—	—	—	—	—	—	—	Made as an upset forging from bar.

TABLE IV. MICROSTRUCTURE AND CLEANNESS.

Item No.	Microstructure		Non-Metallic Inclusions	Cleanness Compared to British Aero Engine Practice	
	Case	Core			
120	Fine spheroidal carbide in martensitic matrix. Fine discontinuous network of carbide near outer edge. Merges gradually into the core.	No free ferrite	Only small sulphide inclusions	—	—
149	Fine, martensitic. Free carbide as nodules but globular near outer edge.	Course, martensitic	Few, small	Equal	—
189(a)	Fine dense sorbite containing small rounded particles of carbide and a partial cementite network.	Slightly marked banded structure consisting of open sorbite with a slight martensitic aspect	Fairly dirty. Uniform with small angular oxides and slightly streaky sulphides.	—	—
189(b)	Similar to 189(a) above	Similar to 189(a) above	Similar to 189(a) above	—	—
190(a)	Normal, semi cellular carbide in outer 0·004 in.	Solid solution with no free ferrite	—	—	—
190(b)	As 190(a) above	As 190(a) above	—	—	—
192(a)		—	Clean	—	—
193	Normal fine martensitic background with appreciable fairly massive carbide particles evenly distributed with no tendency to cellular formation	Entirely solid solution with no free ferrite	Few, mainly small isolated sulphides	Equal	—
194(a)	—	—	Good order of cleanness	Equal	—
196(a)	Fine martensitic with a small amount of free carbide as globules	Fine martensitic	—	Equal	—
196(b)	As 196(a) above	As 196(a) above	—	Equal	—
199	Fine grained	Fine grained	—	—	—
183	Pronounced martensitic markings	Pronounced martensitic markings with no free ferrite	Small sulphide inclusions	Equal	—
188	—	—	Good standard of cleanness	—	—
189(c)	Fine dense sorbite	Sorbite less dense than the case with small ferrite areas and a slightly pronounced irregular banded appearance	Similar to 189(a) above	—	—
192(b)	—	—	Dirty, containing numerous inclusions of refractory type	—	—
194(b)	—	—	Good order of cleanness	Equal	—
180	Fine grained. Small amount of free carbide at the corners of the teeth	Fine grained. Martensitic with an appreciable amount of free ferrite	—	—	Evidently had single quench
208	—	—	—	—	Probably "time" quenched
289(a)	—	—	—	—	—
289(b)	—	—	—	—	—

policy towards reduction of alloy content is to be found in the gear of which three examples have been examined, i.e., item 1 (see first summary) and items 180 and 208. Whereas item 1 was a steel of the 2/2 Cr Ni Mo type, items 180 and 208 were both made in 1% Mn 1¼% Cr steel, deliberate additions of nickel and chromium having been omitted. Similarly, the gear of which two examples have been tested, namely items 120 and 183 showed a change from 2/2 Cr Ni Mo to the 1% Cr Mo type. Economy in alloy was also indicated by comparing items 289(a) and 289(b) with items 19(c) and 19(b) in the first summary.

Macrostructure—Forging, etc.

The macrostructures disclosed that the best practice for the production of the several types of gears had been followed, the forgings having been made by accepted methods to produce blanks with profiles closely corresponding to those of the gears.

It was however, interesting to note an apparent change in production methods for the camshaft pinion covered by both items 120 and 183. In the former case it appeared that several pinions had been machined from one upset forged blank whereas in the latter it was obvious that the forgings were made singly.

In several cases it was noted that considerable amounts of steel had been removed from the forgings in subsequent machining operations but this was probably unavoidable.

McQuaid Ehn Grain Size

The results reported in the first summary suggested that grain size control was being practised with the 2/2 Ni Cr type of steel. The bulk of those examined in this report were fine-grained (5–7) with the two exceptions 189(a) and 189(b).

The Cr Mo (as before) and Mn Cr steels did not convey any suggestion of the application of grain size control, the results being very irregular.

Case Carburising and Hardening

No exception could be taken to the macro characteristics of the carburised zones although as has been previously noted, the depths of case varied widely up to 0·06 in. deep and there was a general tendency towards shallower cases than those in the earlier report. The variations have presumably been dictated by the nature of the duty intended.

As before, the carburised cases of most of the gears exhibited free carbide in nodular and/or globular form. In three cases a tendency to cellular carbide structure was noted.

As regards the core structure, about half of the earlier examples were reported as having some free ferrite present in the structures. On this occasion only two of the thirteen examined under the microscope had this feature. It was noted that item 180 had clearly received a single quenching treatment whilst its duplicate (item 208) appeared from its hardness characteristics to have had a time quench.

Cleanness

Twelve of the gears were examined for cleanness and all but three were found to conform to a good standard. The three inferior steels were items 189(a), 189(b) and 192(b). Item 189(a) has already been commented upon in respect of low silicon content (0·13%) and high sulphur ; and whilst item 192(b) had a high silicon content (0·34%) the Mn was the lowest of the group at 0·72% and the sulphur and phosphorus values were the highest of the 21 steels examined (at 0·026 and 0·022% respectively).

Gears and Free Wheel from a Supercharger Drive

An assembly of primary gears and free wheel from the supercharger drive of a Jumo 211 J engine was examined. Photographs of each side of the assembly are reproduced in Figs. 1 and 2, while Fig. 3 shows a sectional arrangement of the unit and the main components are illustrated in Fig. 4. A description of these components, with particulars of surface finish and dimensions, is given in Table I, and details of composition,
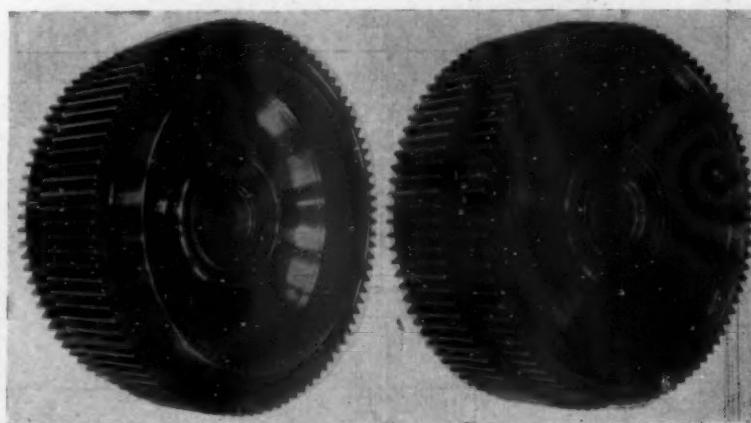
Tensile Properties

As tensile tests were taken on three examples only, no comment can be offered beyond that the results represented good quality material.

Summary of Conclusions

The steels fell into three groups as regards composition. The third group covered 1% Mn. 1¼% Cr steel without deliberate additions of Nickel and Molybdenum. No steel of this kind was used in the gears reported in the first summary.

Changes in composition in given types of gear and the greater lack of uniformity of analysis pointed distinctly to the definite practice of economy in alloys.

All the steels were made by the basic arc electric process.

All the gears have been forged according to the most satisfactory practice.

In all cases the steels were of the case-hardening type and were carburised on the important wearing surfaces.

The general quality of steel and the finish of the gears were up to the standard of those reported in the first summary.

grain size and hardness are summarised in Table II.

Analysis

All the six case-hardened components were of basic electric arc quality, and two of these, viz : the spur gear wheels, were nickel chromium molybdenum steels approximating to the 2% nickel, 2% chromium type, although in the narrow wheel the nickel content and in the broad wheel

Fig. 1.—Gear wheel assembly.

Fig. 2.—Gear wheel assembly (reverse side).
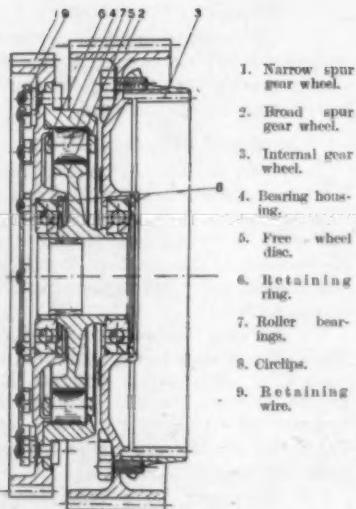
Fig. 3.—Section through assembly.

1. Narrow spur gear wheel.
2. Broad spur gear wheel.
3. Internal gear wheel.
4. Bearing housing.
5. Free wheel disc.
6. Retaining ring.
7. Roller bearings.
8. Circlips.
9. Retaining wire.

Fig. 4.   The various parts of the supercharger drive.

A—Rollers.   C—Narrow spur gear wheel.   E—Internal gear wheel.   G—Free wheel Disc.
B—Roller bearing.   D—Broad „ „ „   F—Bearing housing.   H—Circlip.

the chromium content were each only about 1½%. The internal gear wheel and the retaining ring were both of the 1% chromium molybdenum type

of steel, and the bearing housing and free wheel disc were of the 0·20/0·25% carbon, 1½% manganese, 1½% chromium type. This composition was not encountered in the gears previously recorded.

The roller bearings were made from 1% carbon, 1% chromium steel, probably of open-hearth manufacture.

Grain Size

The grain size of the steels from which the gears were produced was variable, being mainly medium to fine.

Macroscopical Examination

Magnetic etching tests were carried out on the six main parts, but no cracks or surface defects were revealed. All the gears had been machined from

TABLE I.   SUMMARY OF COMPONENTS EXAMINED.

Item No.	Type of Engine	Component	Description	Dimensions	No of teeth
189	Jumo 211 J 1 (Engine M.M.W. 740).	Narrow Spur Gear Wheel	The narrow spur gear wheel could be engaged through a free-wheel coupling on to a lay-shaft driven from the crankshaft drive by a bevel gear. The teeth were straight cut. Web (4·5 mm. thick) drilled with 16 – 6·5 mm. holes equally spaced on 142·5 mm. P.C.D. and 119 mm. diameter by 4·5 mm. spigot machined for fixing and locating of bearing housing. Machined all over, emery finish except inner surface of hub and sides and faces of teeth which were fine ground, and tips of teeth which were very fine machined.	178 mm. overall dia. × 23 mm. wide, with teeth 18 mm. wide on 184 mm. P.C.D., 62 mm. dia. bore to take radial ball bearing and grooved for circlip.	88
		Broad Spur Gear Wheel	Fitted to the internal gear wheel. The teeth were straight cut. Web with 141 diameter × 4 mm. spigot drilled with 16 – 6·5 mm. holes, equally spaced on 153·5 mm. P.C.D. for bolts for mounting to internal gear and 4 – 6 mm. dowel pin holes for locating the internal gear—one of these holes was unequally spaced. Machined all over, one face had an emery finish and the other an emery and ground finish the inner surface of the hub and sides and faces of the teeth were fine ground and the tips of the teeth were fine machined.	188 mm. overall dia. with teeth 41 mm. wide on 184 mm. P.C.D. bore 62 mm. dia. × 15 mm. long to take radial ball bearing and grooved for circlip.	93
		Internal Gear Wheel	The internal gear wheel, which was fitted to the broad spur gear wheel, could be engaged through a disc coupling with the lay-shaft driven from the crankshaft by means of a bevel gear. The two wheels were positioned by four dowel pins, one of which was unequally spaced ; and held together by twelve equally spaced set screws, passing through 5 mm. dia. tapped holes. The teeth were straight cut. Fine emery finish all over except sides and faces of teeth which were fine ground and tips of teeth which were fine machined.	164 mm. overall dia. × 27·5 mm. wide with teeth 22 wide on 141 mm. P.C.D.	94
		Bearing Housing	The bearing housing was attached to the web face of the narrow spur gear wheel, being held together by sixteen equally spaced nuts and bolts, through 6·5 mm. dia. holes. Fine ground finish except for some rough machined portions on non-working surfaces.	155 mm. overall dia. × 21 mm. wide with smooth bore for roller bearing 120 mm. dia. × 17·5 mm. long and 2 mm. chamfer on inside face.	—
		Free-Wheel Disc	The free-wheel coupling consisted of a free-wheel, internally splined to fit the lay-shaft, housed between the two spur gear wheels each fitted with a similar sized ball bearing. The periphery of the free-wheel was divided into eight segments, each having a gradually increasing diameter. These segments act as a clutch between the free-wheel, through the roller bearings and retaining ring to the bearing housing attached to the narrow spur gear wheel. Web drilled with 8 – 7 mm. dia. holes, equally spaced. The outer wearing surface had a well lapped finish and showed slight wear. The faces of the disc had a shot-blasted finish, whilst the inner surface of the hub was fine ground. The splines were vee shape and straight cut.	100 mm. overall dia. × 37 mm. wide, with eight teeth, equally spaced, 14 mm. wide. Bore 31 mm. dia × 37 mm. long with internal vee spline of 35 teeth × 13·5 mm. long to suit lay-shaft. Seatings at each end of bore for external mounting of radial ball bearings fitting narrow and broad spur gear wheels.	8
		Retaining Ring	Eight radial recesses equally spaced for roller bearings. Sides fine ground ; inner surface had a well lapped finish.	113 mm. overall dia. × 20·5 mm. wide with eight radial recesses 23 mm. radius × 4 mm. maximum depth, equally spaced	—
		Roller	Eight in number. The surfaces had a well lapped finish and the ends were fine ground.	14 mm. dia. × 14 mm. long.	—
		Circlips	Slightly scaled black finish.	For fitting 65 mm. dia. × 1·5 mm. groove and positioning 62 mm. dia. radial ball bearings in narrow and broad gear wheels.	—
		Retaining Wire	Bright finish.	For fitting through 1·5 mm. dia. hole in bolts.	—

blanks made closely to the required profile by upset forging operations and macro-etching revealed satisfactory flow structures.

Case Carburising and Hardening

The six main components had been case-carburised, carburisation being confined to the teeth of the three gear wheels and to the working faces of three components. The cases were generally shallow, with the exception of the free wheel and the narrow spur gear wheel, the latter showing a very variable depth of case.

Hardness determinations were made on the carburised surfaces as well as on the core of the various components ; the values on the hardened cases showed a variation from 722 to 833, while the core hardness varied from 361 to 466.
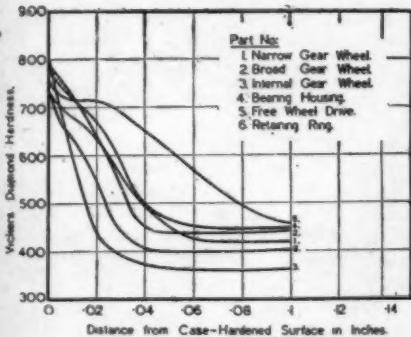
In addition, hardness tests were carried out on sections through the carburised teeth of the three gears, and through the carburised wearing surfaces of the bearing housing, free-wheel disc and retaining ring, and the results plotted in the form of depth hardness curves are shown in Fig. 5.

Microscopical Examination

(a) *Cleanness.* The steels were generally slightly dirty, with uniformly distributed inclusions consisting of small angular oxides, and small streaky sulphides.

(b) *Microstructures.* The structures of the carburised case and of the core were satisfactory, with the exception

of the case of the free-wheel disc which showed the presence of a marked carbide network. The structure of the case of the free-wheel disc is illustrated in Fig. 6.

The roller bearings had a fine uniform hardened structure with very small particles of carbide as shown in Fig. 7. The circlips showed a banded structure of sorbite containing interspersed ferrite and there was evidence of decarburisation to a depth of 0·004 in. with a resulting decrease in hardness near the edges to a value of 324. The retaining wire had been hard drawn from the patented condition.
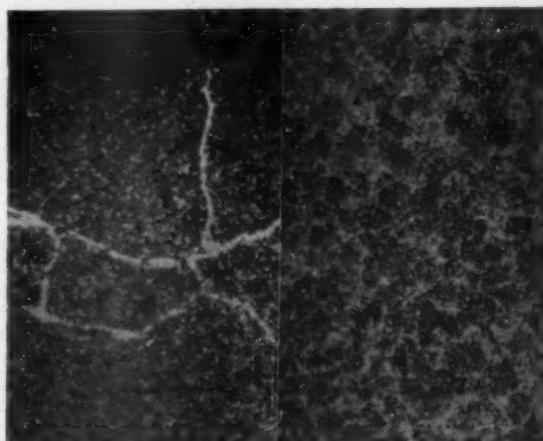

Fig. 6.—Structure of carburised case of free wheel disc. × 300.

Fig. 7.—Structure of roller bearings. × 300.

Fig. 5.—Depth hardness curves.

TABLE II. CHEMICAL COMPOSITION, GRAIN SIZE AND CASE-HARDENING DATA.

Item No.	Type of Engine	Component	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	N	McQuaid Ehn Grain Size	Case-Hardening.			
															Position	Depth in.	Diamond Hardness	
																	Surface	Core
189	Jumo 211 J 1 (Engine M.M.W. 740).	Narrow Spur Gear Wheel	0·16	0·13	0·55	0·021	0·013	1·56	2·17	0·19	Nil	0·01	0·008	2–5, Variable	On teeth only	Variable 0·003–0·045	Tips of teeth 778 Sides of teeth 752–798	421
		Broad Spur Gear Wheel	0·19	0·25	0·51	0·011	0·009	1·94	1·57	0·20	Nil	0·14	0·012	2–5, Variable with a little 1	On teeth only	0·025	Tips of teeth 792 Sides of teeth 774–798	440
		Internal Gear Wheel	0·16	0·27	0·82	0·013	0·016	0·66	0·95	0·20	Nil	Tr.	0·015	3–5, mainly 4–5	On teeth only	0·015	Tips of teeth 833 Sides of teeth 511–575	361
		Bearing Housing	0·25	0·29	1·32	0·011	0·014	0·06	1·35	Nil	Nil	0·12	0·011	5–6, mainly 6	On inner bearing surface	0·018	722–752	450
		Free Wheel Disc	0·20	0·18	1·32	0·005	0·013	0·26	1·36	Nil	Nil	0·13	0·012	2–5, mainly 3–4	On outer wearing surface	0·057	742–768	466
		Retaining Ring	0·17	0·39	0·90	0·006	0·011	0·53	1·04	0·19	Nil	0·14	0·011	5–6	On inner surface	0·014	Inner surface 757–774 Outer surface 421–462	401
		Roller Bearings	0·98	0·29	0·31	0·024	0·025	0·025	0·97	Nil	Nil	0·16	0·003	—	—	—	—	810
		Circlips	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	397–429
		Retaining Wire for Nuts	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	554–566

Section IX.—Bearings

EXAMINATIONS have been made of crankshaft main bearings in nine examples and for connecting rod bearings in eight examples from the same general engine types which have been considered in the investigations already reported on other components. The results of the examination call for little detailed comment and a summary of the results obtained is given below.

Crankshaft Main Bearings

The items examined under this heading comprised Nos. 123, 129, 212, 231, 252 from Jumo 211F1 engines, No. 306 from a Jumo 213A1 engine and No. 238 from DB.605A1 engine. The fullest examination was made on items 123 and 129, and since throughout the series the same general features are apparent, it will only be necessary to refer to a single example. Differences in design between different engines were noted, but materials used were the same throughout with only minor alterations.

Considering Item No. 129, which included the main bearing and bearing shells from a Junkers Jumo 211 F1 engine from a Heinkel 111–H6 aircraft, the bearing cap was of a light alloy drop stamping in material of the duralumin type as indicated by the following analysis :—

	Si	Mn	Fe	Mg	N
Item No. 129— bearing cap...	0·52	1·10	0·20	0·96	nil
	Zn	Ti	Cu	Al (by diff.)	
Item No. 129— bearing cap...	0·20	0·03	3·65	93·28	

The hardness in a Brinnell test with 40 Kg. load and 2 mm. ball was 129/130.

The bearing shell was of mild steel with a cast-in lining of lead bronze and the compositions of these parts were as follows :—

	C	Si	Mn	S	P
Item No. 129— bearing shell ..	0·12	0·18	0·032	0·030	0·010
		Cu	Ni	Sn	Pb
Item No. 129—bearing shell	0·05	tr.	—	—	
	C	Si	Mn	S	P
Item No. 129— bearing lining ..	—	—	—	—	—
		Cu	Ni	Sn	Pb
Item No. 129—bearing lining ..	0·05 (by diff)	tr.	0·06	19·35	

The sulphur content of this particular bearing shell was higher than in most cases examined, and it may be noted that the lead content of the linings varied from about 14 to 20%. The diamond hardness of the mild steel was 136 and of the lead bronze 40/45. Some variation in hardnesses of these types of components under other item nos. was noted, but none calling for special comment.

Throughout it was observed that the adhesion between mild steel and lead bronze was very good.

Connecting Rod Bearings

Engine types included in the examination of connecting rod bearings included the Jumo 211F1 (Item No. 228 for example), Jumo 213A1 (Item No. 305), BMW. 801A and 801G and G2 (Items No. 217, 267, 271) and DB.605A and DB603 (Items No. 235, 261, 292).

Certain general features are common throughout, as for example the use for the steel parts of mild steel of a composition and hardness similar to that indicated for main bearings above. Similarly, lead bronzes are used for the linings but with the addition of about 1% antimony in some cases (Items No. 228, 235 and 261) or 2% tin (Item No. 305). Adhesion between the ferrous and nonferrous parts was good.

Comments

The general features revealed in these studies are similar to those indicated in the earlier summary report on bearings.

Aluminium Development Association

THE above Association held an informal reception at Claridges' Hotel on November 30 last, primarily with the object of introducing the recently appointed Director General of the Association, Air-Commodore W. Helmore, C.B.E., Ph.D., M.Sc., but also to take the place of a house-warming party in view of the Association becoming centrali ed in new offices at 67, Brook Street, London, W.1.

Air-Commodore Helmore will be familiar to the majority of readers for his monthly broadcast commentaries during the past twelve months. But he has broadcast nearly all the official R.A.F. commentaries from the beginning of broadcasting, including those on such famous air events as the Schneider Trophy, Royal Reviews and Air Forces Displays, airship launches, the International Air Race to Australia, and many others. Between the two great wars, Group-Captain Helmore, as he is more familiarly known, was chiefly employed in scientific and aeronautical research. He was a pilot in the last war and his special scientific work has involved his flying in operations in the more recent one. He is a technical adviser to the Ministry of Aircraft Production and is also a member of Lord Brabazon's Committee which is advising the Government on the technical aspects of future civil aircraft.

Introduced by the President, the Hon. Geoffrey Cunliffe, Air-Commodore Helmore expressed his views on the tasks before the Association. It has been formed to provide a central body of design and development technicians representing the whole industry and maintained by its member firms, with the object of giving the user a better and cheaper article in aluminium or aluminium alloy than could be obtained in any other material. Its functions are to initiate, produce and pioneer aluminium prototypes and to evolve new uses and processes for the metal. As a focal centre of development it will be the Association's work to assimilate and re-invest in peace-time designs the inventive riches of our war legacy.

Particular mention was made of the many domestic shortages which could be made good in aluminium by producing household equipment, furniture, building structures and the like. While aluminium, in its various forms, has manifold applications in industry, it is in the transportation services that it is ideally suited, thus in the construction of road vehicles, railway rolling stock, ship building, etc., efforts will be made to stimulate existing trends in order that wider use may be made of light alloys. As Air-Commodore Helmore says, the projects contemplated may appear somewhat visionary, but progress is often founded upon visions and with the full support of engineers and the strong backing of the Government, Britain and its Empire may well give the world a lead to the light metal age which is surely coming. There can be no doubt that, under the direction of such an experienced man possessing vision of a high order, the Association will play a vital part in the development of the aluminium industry.

An Essential Piece

In the jig-saw puzzle of post war design, a pressure die casting in Mazak Zinc Alloy will, in thousands of cases, represent the piece which the designer seeks to complete his picture. For Mazak possesses a variety of virtues which render it peculiarly suitable for the production by pressure die casting of innumerable components which post war specifications will demand. Unusual fluidity at a low casting temperature results in high speed production accompanied by remarkable adherence to the most complicated detail of design. Excellent physical properties accompanied by remarkable dimensional stability result in strong stable castings suitable for stressed components. A high degree of resistance to corrosion accompanied by surfaces which lend themselves to a variety of attractive finishes result in castings which resist the elements and please the eye. For these reasons, Mazak will prove to be the answer to many problems of material and design which will appear in the picture of production which confronts the post war world.

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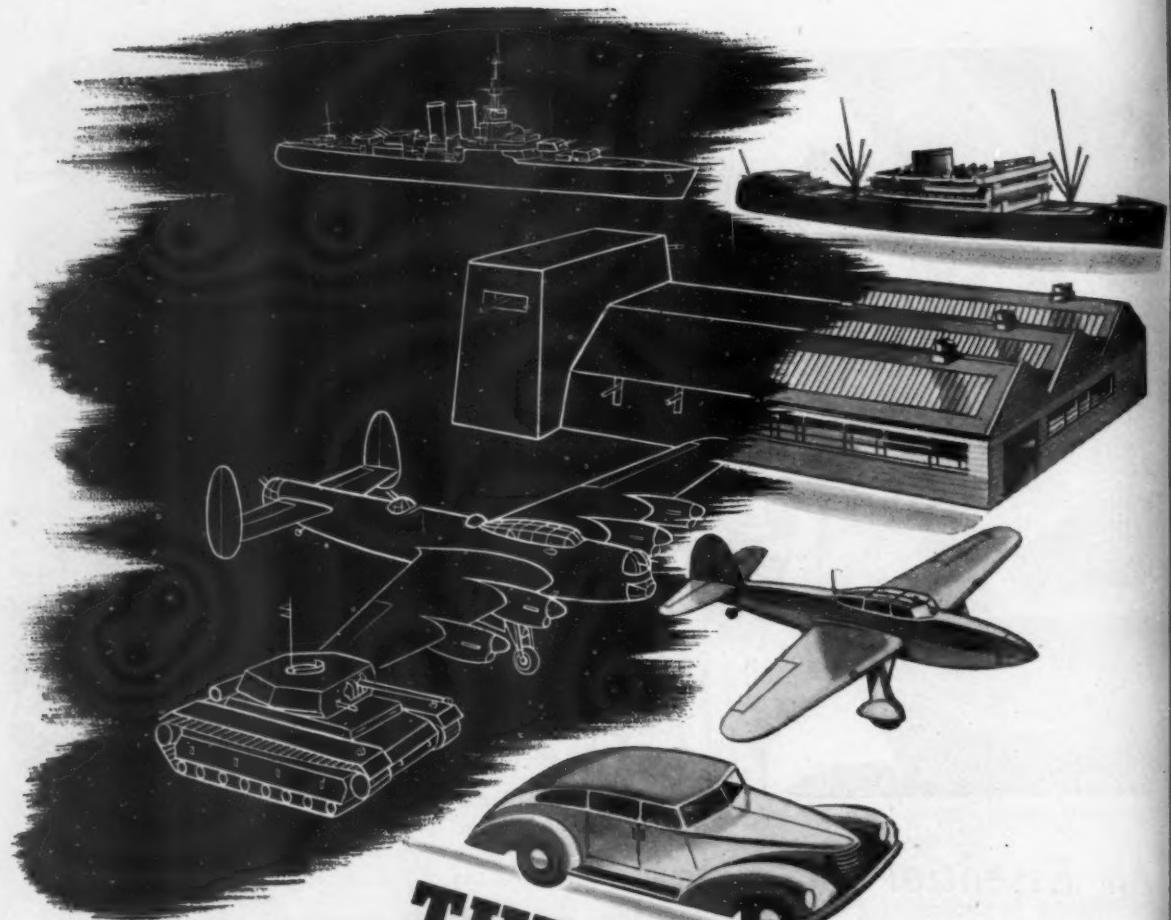
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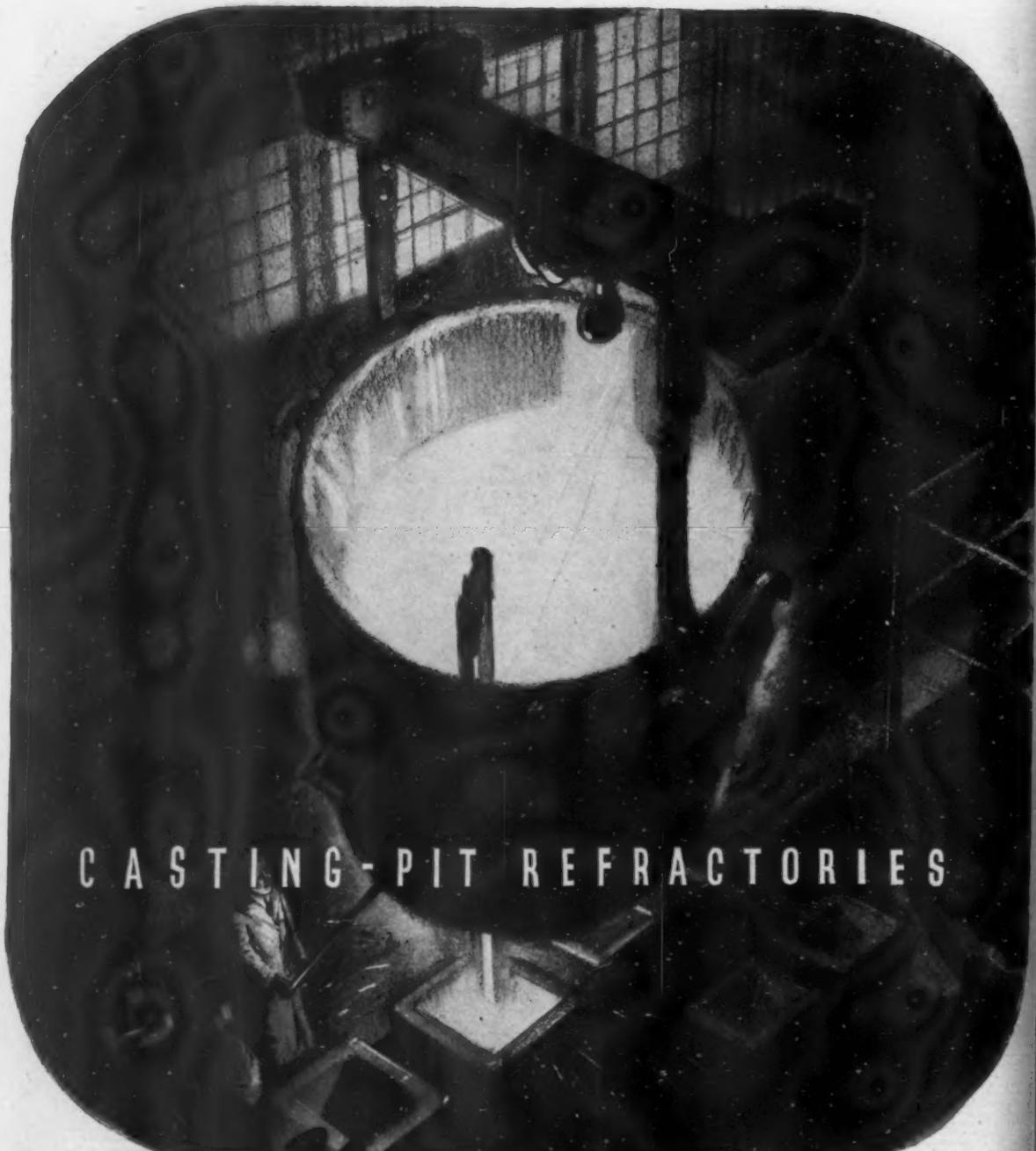
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Carbon steels meet the bulk demands of the engineer, but, when improved mechanical properties are required in steels of similar carbon content, one or more of several alloying elements are added. It should be remembered, however, that it is the ultimate mechanical properties of the steel part which matter and not the composition. The need for economy in the use of these alloying elements has emphasised the need for obtaining the best properties in the steel consistent with the duty the part is required to perform, and greater attention has been directed to heat-treatment to effect improvement. In this article special attention is given to the heat-treatment of low alloy steels.

THE development of a wide range of alternative steels resulting from the need of economy in the use of alloys has been one of the features of war-metallurgy. These steels have made it necessary for steel manufacturers to consider carefully the entire problem of heat-treatment to ensure that the best possible results should be obtained from them. In the present article, the "substitute" steels of low alloy wrought type are considered from this point of view.

The En 110 and 100 series of steels has been specially designed to take advantage of the alloy contents in steel scrap. These alloy steels are of much lower alloy content than those hitherto employed, and as a result, special care in heat-treatment has become necessary to secure similar physical properties as regards higher alloyed steels for similar purposes. The substitute steels apply to ruling sections of not more than 6 in. in thickness. For a considerable period alloy steels for the 40–50 tons tensile range with less than 6 in. in ruling thickness have been prohibited.

The first steel to be dealt with is that corresponding to En 11A and 11B. This is a carbon chromium steel designed primarily for wearing surfaces, springs, spring washers, etc. Such a steel can be forged without difficulty, and can be hot-worked within the temperature range 1,150°–1,250° C. Close control of hot-working temperatures is, however, essential, so that a pyrometrically controlled furnace should be used. In no circumstances should hot-working be carried on after the piece has fallen to a temperature of 900° C., and if work is not complete when the material has cooled to this temperature, it should be returned to the furnace and reheated.

Hot working necessitates a stress-relieving treatment, and, in general, a sub-critical annealing is advisable, for which purpose the steel should be reheated after hot-working to 660°–690° C., and allowed to cool in the air. It should be noted that the temperatures here given are those of the steel itself, and not of the furnace containing the steel.

It is possible to abbreviate the treatment by heating the steel to a normalising temperature, and rapidly cooling down in the furnace at the rate of approximately 100°–125° C. until the critical range is attained, after which cooling is slower. The steel is cooled in the furnace until it attains 680°–700° C., when it is cooled off in the air.

To harden, the steel must be heated slowly and uniformly to 830°–870° C., using the lower temperature if the hardening medium is a salt bath furnace. The part must be thoroughly soaked at this temperature, and if feasible, a controlled atmosphere furnace should be used to prevent scaling or decarburisation of the surface. Oil quenching will be quite satisfactory, and the oil should be warmed and circulated. Cleaning after quenching is advisable.

Tempering can be carried out in a salt bath or electric tempering furnace at 590°–700° C., according to the precise composition and the section, and the properties desired. The tempering temperature should be held for approximately 30–40 min.

A typical composition for this steel is shown in Table I, together with the range of mechanical properties obtainable after hardening and tempering.

Steel corresponding to En 12 is a nickel manganese steel designed for shafts, axles, connecting rods, and other parts of automobiles, as well as for breech blocks, gun jackets, etc. Steels of this type possess good mechanical properties, which depend to some extent on the mass of the treated part. There is a wide range of compositions, and the steelmaker should be consulted in this respect, the purpose for which the steel is required being carefully indicated. In general, all these steels can be oil hardened at 850° C. and tempered within the range 625°–650° C.

A manganese-nickel-molybdenum steel corresponding to En 13 is less frequently employed, but fulfils the same purpose as the above, and may be oil hardened at 850°–880° C., tempering being carried out at 640°–660° C., followed by air cooling.

The next steel is En 14, a carbon manganese steel suitable for welding purposes. This type of steel has good physical properties, and is usually oil hardened, water hardening being liable to cause a measure of distortion. No special difficulties are experienced in forging, nor does cold-drawing cause any appreciable trouble, and machining properties are excellent. Oil hardening within the range 850°–860° C., followed by tempering from 600°–640° C. will give satisfactory results. Water hardening, if adopted, should be at 850° C.

We next come to a wide range of low alloyed steels corresponding to En 16A, 17A, 17B, 18A, 19A and 21A, which are largely similar in purpose to En 14, but are of varying compositions, as will be seen from Table I. One group of these may be classed substantially as manganese molybdenum steels. Steels of this type have extremely good physical properties, but are not entirely free from difficulties of manipulation. In general, the hardening temperature, whether water or oil be the medium, which is decided by the composition

of the steel, should be 850° C., with a later tempering from 600°–650° C. The tempering temperature will depend on the purpose for which the steel is required, and also on composition and thickness of maximum cross-section. Slow cooling after hot-working is advantageous.

Those steels of this type with a rather higher percentage of molybdenum in their composition are liable to air-harden where the section is thin, so that if a softening treatment is necessary, they should be tempered at 670° C.

The second group are manganese-chromium steels, which demand an oil-hardening treatment within the temperature range 830°–865° C., followed by a tempering from 650°–700° C. Lower temperatures for tempering are inadvisable, as the steel is liable to lack toughness if they are employed. The larger sizes may, if desired, be water-quenched at 650°–700° C., when the steel contains nickel, and steels of this nickel-containing type must be hardened at 830° C. if oil is used as the quenching medium.

The third group is largely similar to the above, except

<div style="text-align:center">TABLE I.</div>

STEEL TO SPECIFICATION		COMPOSITION								MECHANICAL PROPERTIES	
		C	Si	Mn	Ni	Cr	Mo	S max.	P	Max. Stress Tons per sq. in.	Elongation %
En 11A, 11B		0·5–0·7	0·35 max.	0·5–0·8	—	0·5–0·8	—	0·05	0·05	55–70	12–24
En 12, 13	Group 1	0·3–0·45	„	1·50 max.	1·0 max. (opt.)	—	—	0·05–0·06	0·05–0·06	41–49	22–31
	„ 2	0·25 max.	„	1·4–1·8	0·3–0·7	—	0·25–0·4	0·05	0·05	41–44	26–29
En 14		0·3 max.	„	1·75 max.	0·3 max.	—	—	0·05–0·06	0·05–0·06	44–47	25–28
En 16A, 17A, 15B, 18A, 19A, 21A.	Group 1	0·25–0·4	„	1·3–1·6	—	—	0·2–0·55	0·05	0·05	46–62	17–32
		0·3–0·4	„	1·25–1·75	—	—	—	0·05–0·06	0·05–0·06		
	„ 2	0·35–0·45	„	0·6–1·2	0·3 max.	0·8–1·2	—	0·05	0·05	47–58	22–30
	„ 3	„	„	0·5–0·8	—	0·9–1·5	0·25–0·4	„	„	43–74	17–28
	„ 4	0·25–0·35	„	0·35–0·75	2·75–3·5	0·3 max.	—	„	„	45–55	21–27
En 16B, 17B, 18B, 19B, 24A, 23A.	Group 1	0·25–0·4	„	1·5–1·8	—	—	0·2–0·55	„	„	51–62	20–24
	„ 2	0·35–0·45	„	0·6–1·2	0·3 max.	0·8–1·2	—	„	„	48–61	21–26
	„ 3	„	„	0·5–0·8	—	0·9–1·5	0·25–0·4	„	„	53–60	22–25
	„ 4	„	„	„	3·25–3·75	0·3 max.	—	„	„	48–62	21–25
	„ 5	„	„	0·4–0·8	1·0–2·0	0·75–1·5	0·2–0·4	„	„	60–62	23
	„ 6	0·25–0·35	„	0·45–0·7	2·5–3·75	0·5–1·0	0·65 max. (opt.)	„	„	49–60	18–24
En 16C, 17C, 18C, 19C, 22B, 24B, 23B, 25A, 27A, 29C, 20A.	Group 1	0·25–0·4	0·35 max.	1·5–1·8	—	—	0·2–0·55	0·05	0·05	52–65	19–22
	„ 2	0·35–0·45	„	0·6–1·2	0·3 max.	0·8–1·2	—	„	„	60–60	20–21
	„ 3	„	„	0·5–0·8	—	0·9–1·5	0·25–0·4	„	„	61–65	20–22
	„ 4	„	„	„	3·25–3·75	0·3 max.	—	„	„	52–65	17–22
	„ 5	„	„	0·4–0·8	1·0–2·0	0·75–1·5	0·2–0·4	„	„	65–66	20–22
	„ 6	0·25–0·35	„	0·45–0·7	2·75–3·75	0·5–1·0	0·65 max. (opt.)	„	„	60–63	21–22
	„ 7	„	„	0·4–0·8	2·0–3·0	0·5–1·0	0·4–0·7	„	„	58–65	20–23
	„ 8	„	„	0·7 max.	3·0–3·75	0·5–1·3	0·2–0·65	„	„	57–60	23
	„ 9	0·15–0·55	„	0·65 max.	0·4 max.	2·5–3·5	0·3–0·7	„	„	55–62	21–24
	„ 10	0·3–0·4	„	0·45–0·7	2·0–3·25	0·5–1·25	0·6	Van. 0·25 max. (opt.) W.1·0 max. (opt.)	„	55–69	19–23
	„ 11	0·22–0·5	„	0·4–0·8	0·3 max.	0·5–1·5	0·4–1·0	„	„	59–69	17–22

that a small molybdenum percentage is added to the steels. Steels of this group have a high resistance, relatively, to impact, fatigue, abrasion and high temperature stress. Assuming they have been satisfactorily heat-treated they are capable of taking on a deep hardness. They are easily machined and can be welded by either gas or electric processes. One advantage they have is that they can be tempered at lower temperatures than the previous group, without any decline in toughness. Oil hardening is usually adopted, the hardening temperature range being 830°–880° C., according to the mechanical properties required. Tempering is carried out at 600°–700° C., according to purpose.

The fourth group are 3% nickel steels. A straightforward normalising or true "annealing" treatment from temperatures above their critical points or ranges will be adequate to eliminate the strains occasioned by mechanical working, while at the same time softening them sufficiently to ensure easy machining. Nevertheless, it is often advantageous to employ a sub-critical annealing or softening treatment, but if this procedure is adopted, a heating period of at least twice as long as that needed for full normalising is essential.

The steels are usually cooled in air, but in special instances it may be essential to cool down slowly in the furnace. The soaking period is of maximum importance, a point that should be carefully borne in mind. The hardening temperature range is 830°–850° C., in oil, with tempering at 600°–650° C.

The next range of steels to be discussed is that corresponding to the following En specifications : 16 B, 17B, 18B, 19B, 22A, 24A, 23A. Of these, the composition varies, and among these steels of this group are included a manganese molybdenum steel, a nickel-chromium-molybdenum steel, a manganese-nickel-chromium steel, and a manganese-chromium-molybdenum steel. Nickel-chromium and nickel-chromium-molybdenum steels are also included.

In general, the common feature possessed by steels to the above specifications is that they are capable of giving a tensile strength of 50–60 tons per sq. in. The first group, which covers the manganese molybdenum steels, is usually oil-hardened within the temperature range 840°–850° C., followed by a tempering treatment at 625°–650° C. To make certain that the hardening treatment is effective, it is of great importance that when the parts or bars are introduced into the quenching bath, their surfaces should as far as possible be kept from coming into contact with each other. Steels of this group call for a slightly swifter cooling than those of the nickel-chromium-molybdenum group when being quenched.

The second group of these steels are of manganese-chromium type. They are less widely used than, and not so effective as, the first group of these steels, but can be employed in special circumstances as alternatives. They should be oil-hardened within the temperature range 830°–850° C., and tempered from 620°–700° C., according to purpose.

The third group are manganese-chromium-molybdenum steels. These are useful steels, because they possess a wide range of mechanical properties when suitably tempered. Oil hardening is usually carried out at 850° C., and tempering within the range 500°–650° C. will give a range of maximum stress from 53–60 tons per sq. in. A useful fact about these steels is that they are relatively free from mass effect.
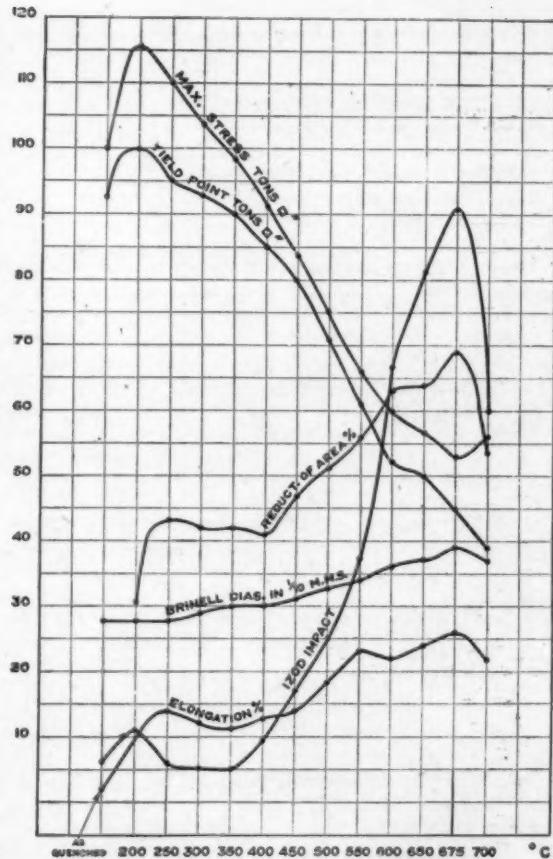

Fig. 1.—Chart showing effect of heat-treatment on a nickel-chromium alloy steel. Quenched in oil at 850° C. and tempered for 40 mins. at temperatures given.

The next group comprises one of the most popular of all these steels, and is of 3·5% nickel type. This steel has also a wide range of potential mechanical properties if suitably treated. It combines great strength with toughness, after heat-treatment, and its resistance to shock is represented by a high Izod impact test figure. It needs reasonable care in forging and stamping, etc., and is employed for crankshafts, clutch couplings, gear shafts, axle shafts, propeller shafts, steering swivels, pinks, links, arms, etc. Forging is best carried out at 950°–1050° C. Softening for machining is carried out at 600° C. Oil hardening is usually adopted, the steel being quenched at 820°–840° C., with a tempering treatment within the range 600°–650° C., with rapid cooling in the air, or, perhaps better, a water quench. The treatment may be varied according to the tonnage required.

As a rule the steelmaker supplies this steel softened ready for machining, but it can also, if desired, be supplied ready heat-treated. In that condition it is machinable without difficulty and all later heat-treatment is thus avoided. If the steel has to be forged or stamped, it is useless for it to be treated before despatch, as the forging or stamping will destroy the effect of heat-treatment.

The next group includes the nickel-chromium-

TABLE II.

STEEL TO SPECIFICATION	COMPOSITION						MECH. PROPERTIES		HEAT-TREATMENT	
	C	Si	Mn	Mo	Cr	Ni	Max. Stress	Elon. %	Harden at °C.	Temper at °C.
En 16D, 17D, 19D, 24C, 25B, 25C, 27B, 28A, 29D. Group 1	0·25–·04	0·35 max.	1·3–1·8	0·2–0·55	—	—	58–68	19–20	Oil 840–850	600
„ 2	0·35–0·45	„	0·5–0·6	0·25–0·4	0·9–1·5	—	65·5–68	20–20	„ 850	650
„ 3	„	„	0·4–0·8	0·2–0·4	0·75–1·5	1·0–2·0	65–66	22–24	„ 830	650
„ 4	0·25–0·35	„	„	0·4–0·7	0·5–1·0	2·0–3·0	62–70	19–21	„ 830	600–650
„ 5	„	„	0·45–0·7	0·65 max. (opt.)	„	2·75–3·75	61–65	20–21	„ 830	580
	„	„	0·7 max.	0·2–0·65	0·5–1·3	3·0–3·75	„	20–21	„ 830	580
„ 6	0·25–0·4	„	„	0·2–0·65	0·75–1·5	3·0–4·5 Va.0·25max. (opt.)	66·5–67	20	„ 830	600
„ 7	0·15–0·35	„	0·65 max.	0·3–0·7	2·5–3·5	0·4 max.	61–69	21–21	„ 900	600
En 24D, 16E, 17E, 19E, 23D, 25C, 26A, 27C, 29E, 28B. Group 1	0·35–0·45	„	0·4–0·8	0·2–0·4	0·75–1·5	1·0–2·0	70	17–19	„ 850	560–580 water
„ 2	0·25–0·4	„	1·3–1·8	0·2–0·55	—	—	68	23–24	„ 850	600 water
„ 3	0·35–0·45	„	0·5–0·8	0·25–0·4	0·9–1·5	—	71	19–20	„ 830	600 oil
„ 4	0·25–0·35	„	0·45–0·7	0·65 max. (opt.)	0·5–1·0	2·75–3·75	68	17–18	„ 830	560 oil
„ 5	„	„	0·4–0·8	0·4–0·7	„	2·0–3·0	69·5–70	17–19	„ 850	545–560 air
„ 6	0·35–0·45	„	„	„	„	„	70–72	17–20	„ 830	570–630 water
„ 7	0·25–0·35	„	0·7 max.	0·2–0·65	0·5–1·3	3·0–3·75	68–70·5	18–19	„ 830–850	540–580 water
„ 8	0·15–0·35	„	0·65 max.	0·3–0·7	2·5–3·5	0·4 max.	68–71	18–20	„ 900	550–585
En 24E, 25D, 26B, 37D, 19F, 28C, 29F. Group 1	0·35–0·45	„	0·4–0·8	0·2–0·4	0·75–1·5	1·0–2·0	73·5	19–20	„ 850	560 water
„ 2	0·25–0·35	„	„	0·4–0·7	0·5–1·0	2·0–3·0	73–78	17–18	„ 850	570 air
„ 3	0·35–0·45	„	„	„	„	„	71–73	18–20	„ 830	590–630 water
„ 4	0·25–0·35	0·35 max.	0·7 max.	0·2–0·65	0·5–1·3	3·0–3·75	73·5–74·5	17–18	„ 830	530–570 water
„ 5	0·35–0·45	„	0·5–0·8	0·25–0·4	0·9–1·5	—	74·5	18–19	„ 850	600 oil
„ 6	0·25–0·4	„	0·7 max.	0·2–0·65	0·75–1·5	3·0–4·5 Va.0·25max. (opt.)	68–72	76–77	„ 830	520–620 air
„ 7	0·15–0·35	„	0·65 max.	0·3–0·7	2·5–3·5	0·4 max.	68–70	20–21	„ 900	570 air
En 24F, 25E, 26C, 28D. Group 1	0·35–0·45	„	0·4–0·8	0·2–0·4	0·75–1·5	1·0–2·0	83·5	15–16	„ 850	510 water
„ 2	0·25–0·35	„	„	0·4–0·7	0·5–1·0	2·0–3·0	„	17–18	„ 850	550 air
„ 3	0·35–0·45	„	„	„	„	„	85	16–17	„ 830	560 water
„ 4	0·25–0·4	„	0·7	0·2–0·65	0·75–1·5	3·0–4·5	84–85	15–17	„ 830–850	450–570 air
En 24G, 25F, 26D, 30; 29G. Group 1	0·35–0·45	„	0·4–0·8	0·2–0·4	0·75–1·5	1·0–2·0	121·5–125·5	14–15	„ 830	200
„ 2	0·25–0·35	„	„	0·4–0·7	0·5–1·0	2·0–3·0	112–116·5	13–14	„ 830	200
„ 3	0·35–0·45	„	„	„	„	„	133	13–14	„ 830	200
„ 4	0·25–0·35	„	0·35–0·6	0·65 max. (opt.)	1·0–1·5	3·75–4·5	111–115·5	13–14	Air 830	200
„ 5	0·15–0·35	„	0·65 max.	0·3–0·7	2·5–3·5	0·4 max.	117·5–122·5	12–16	Oil 900	200
En 31	0·9–1·2	„	0·3–0·75	—	1·0–1·6	—	—	—	„ 810	100–300
En 33, 34, 35, 37 Group 1	0·16 max.	„	0·2–0·6	—	0·3 max.	2·75–3·5	42–60	19–26	Carburise, 900–930.	
„ 2	0·13–27	„	0·3–0·6	0·2–0·3	—	1·5–2·0	45–55·5	20–25	Refine, 830–860. Cool in air, oil or water. Harden, 740–770.	
En 36, 38. Group 1	0·18 max.	„	„	—	0·8–1·1	3·0–3·75	59–67	17–21	Carburise, 880–900. Refine, 830–850.	
„ 2	0·16 max.	„	0·6 max.	0·5 max.	0·3 max.	4·5–5·7	57–70	18–23	Cool Group 1 in air, oil, or water; Group 2 in air or oil. Harden Group 1 at 770° C. in water; Group 2 at 76 in oil.	
En 39	0·2 max.	0·35 max.	0·5 max.	0·5 max. (opt.)	1·0–1·6	4·0–4·5	77·5–86·5	16–17	Carburise, 880–900. Refine, 830. Cool in air or quench in oil. Harden, 760 in oil. Temper, 180–200.	

molybdenum steels. Steels of this group have been specially designed to overcome the trouble known as "temper brittleness," often encountered in alloy steels. This defect of temper brittleness much reduces the ability of the material to resist shock, and wherever it is present, the Izod impact test figures are low. The trouble has been remedied by quenching the steels from the tempering temperature, but when large masses are being dealt with, this does not wholly remove the trouble. The use of steels of this type entirely removes the need of quenching from the tempering temperature, and satisfactory impact figures can be obtained even when large masses are being dealt with, and when cooling from the tempering temperature has been slow. Steels of this group are used for crank shafts, axles, gear pinions, propeller shafts, connecting rods, crank pins, shafts, couplings, and all forms of structural work for severe duty, and where freedom from temper brittleness is essential.

Most parts made from this steel can be air-cooled after tempering without any considerable decline in Izod impact figures. Generally, the steels are oil-hardened from 850° C., and tempered at 600°–550° C., but as so much depends on the mechanical properties desired, it is advisable to consult the steelmaker before deciding. Fig. 1 shows the effect of heat-treatment on a steel of this type.

The last group is also a nickel-chromium-molybdenum type, with a rather lower hardening temperature, and a tempering temperature range of 580°–650° C.

An extremely wide and varied range of steels must next be discussed. These cover the following specifications : En 16C, 17C, 18C, 19C, 22B, 24B, 25A, 27A, 29C, 20A. In the main, they correspond in purpose to the steels of the previous set of specifications, but they are capable of giving a rather higher tensile strength, of the order of 55–65 tons per sq. in. tensile. They include nickel chromium, nickel-chromium-molybdenum, manganese molybdenum, and chromium-molybdenum steels.

Some of these steels present certain difficulties in manipulation that call for care. Where the mass of the piece is large, it is essential that no local chilling shall occur during cooling down from forging or rolling, as otherwise there is a distinct probability that cracks will be formed, leading to failure in service. Cooling down should be retarded by plunging the heated part into ashes, lime or mica, or alternatively the parts can be charged into an annealing furnace before they have cooled to room temperature.

The steels are usually oil-hardened and tempered. Where parts have not been rough machined, the reheating for tempering must be carried out directly from the quenching bath. The steel must not be left to cool in the oil. The reason for this is that the majority of hot-worked pieces or parts carry slight surface defects. These form stress raisers if the surface of the piece after it has been quenched is severely stressed as a result of its cooling more rapidly than the core. Failure to watch this point is responsible for many troubles from cracking.

The manganese-molybdenum steels of this group must be fully quenched, which means that there must be a sufficient depth and quantity or volume of oil to ensure that no portion of the quenched part is less effectively cooled than the rest. Similarly, care must be taken to keep the parts separate in the quenching tank, as far as is possible, as this also leads to uneven quenching and correspondingly, a lack of uniformity in hardness and mechanical properties. The hardening temperature range for this group is 840°–850° C., with tempering from 500°–620° C., according to the mechanical properties required.

Steels of the second group are of carbon-manganese-chromium type, and may be regarded as alternatives to the above where the cross section of the part or bar is not above 1½ in. Oil-hardening at 830° C., followed by tempering from 620°–650° C. is a suitable form of heat-treatment.

The chromium-molybdenum steels of group three are hardened in oil at 850° C., and tempered between 665°–670° C.

Group four covers the popular 3½% nickel steel. The tensile strength of 55 and 65 tons per sq. in. is only attainable if the bar does not exceed 2¼ in. diameter. In general, the heat-treatment to be given corresponds to that for the similar steel described earlier. oil-hardening from 820°–840° C., being followed by tempering from 600°–650° C., to give the higher values of tensile strength.

Group five is a series of nickel-chromium-molybdenum steels, oil-hardened at 850° C., and tempered at 600°–650° C.

Group six is a popular standard steel and is liable to temper brittleness in large masses when no molybdenum is included and when air-cooling has to follow tempering. It is for this reason that molybdenum is added. Hardening in oil at 830° C. is followed by tempering within the range of 620°–640° C.

Group seven contains rather more nickel and molybdenum than the steels of group six, which means that the required tensile strength of 55–65 tons per sq. in. can be obtained when the parts are of a mass still larger than those that can be effectively strengthened by the

TABLE II.—*Continued.*

SPECIFICATION	COMPOSITION								MECH. PROPERTIES		HEAT-TREATMENT	
	C	Si	Mn	Mo	Cr	Ni	Other Constituents		Max. Stress	Elon %	Harden at °C.	Temper at °C.
En 41B, 40A ..0·18–0·45	0·45 max.	0·65 max.	0·1–0·25	1·4–1·8	0·4 max.	0·9–1·3	Al. 0·9–1·30		50·5	24	Harden oil 900	Temper 650 air
	0·18–0·45	0·45 max.	0·65 max.	0·1–0·25	1·4–1·8	0·4 max.						
	0·15–0·35	0·35 max.	0·65 max.	0·3–0·7	2·5–3·5	0·4 max.	0·25 max. Va.	1·0 max. W.				
En 41C, 40C. Group 1	0·18–0·45	0·45 max.	0·65 max.	0·1–0·25	1·4–1·8	0·4 max.	Al. 0·9–1·3.		56·5–61	16–24	oil 900	700–650
„ 3	0·15–0·35	0·35 max.	0·65 max.	0·3–0·7	2·5–3·5	0·4 max.	Va. 0·25 max.	W. 1·0 max.	61–66·5	20·5–22	oil 900	600–650
En 40D	0·15–0·35	0·35 max.	0·65 max.	0·3–0·7	2·5–3·5	0·4 max.	0·25 max.	1·0 max.	63–68	19–22	oil 900	625–650

steels of the previous group. Oil-hardening at 830° C., with a tempering at 630°–660° C. will be found satisfactory.

Group seven are nickel-chromium-molybdenum steels, in which there is a marked absence of mass effect unless the ruling section is relatively large. Oil-hardening at 830° C. is followed by tempering at 600°–650° C.

Group eight is a nickel-chromium-molybdenum steel series which is oil-hardened at 820°–840° C., and tempered for two hours within the range 600°–630° C. Higher tempering temperatures can, however, be employed (up to 750° C.) if a lower range of mechanical properties is required. Steels of this type give excellent transverse properties, and the ratio of transverse to longitudinal impact values is said to be greater than for any other alloy steel.

Steels of group nine deserve particular mention, because they are primarily designed to give the specified range of tensile strength figures while in service at the temperatures of high pressure superheated steam. They are of 3% chromium-molybdenum type. One of their principal uses is for bolts for pipe flanges. The special properties that make these steels advantageous for operation at elevated temperatures are their creep resistance and their stability, which means that they retain a high proportion of their mechanical strength and toughness at the service temperatures, even when exposed for considerable periods. The first group of these steels is usually hardened in water from 875°–900° C., and tempered at 600°–650° C. The second group are quenched in oil at 850°–860° C. and tempered within the range 620°–700° C.

Where steels of yet higher tensile strength are required—e.g., from 65–100 tons tensile, various steels may be employed covering specifications En 19D, 24C, 25B, 23C, 16D, 17D, 27B, 28A, 29D, 24D, 16E, 17E, 19E, 23D, 25C, 26A, 27C, etc. Table II shows the mechanical properties and compositions of these various steels, with their heat-treatment temperature ranges.

The carbon-chromium steel for ball races should be specially mentioned. This corresponds to specification En 31. After hardening from the temperature given below it is usually given a low temperature tempering. The object of this is both to relieve hardened strains and minimise the risk of cracks occurring when the steel is ground. This steel is often given a sub-critical annealing or spheroidising treatment. This facilitates machining. Spheroidising of the cementite is of primary importance in making and heat-treating these steels. Two alternative methods are available. The first is a protracted soaking at 800° C., followed by slow cooling in the furnace to slightly above room temperature. The other is soaking at 820° C., followed by cooling to 650° C. at a rate not greater than 20° C. per hour. The first method occupies about 36 hours, and the second from 12 to 18 hours, according to the section of the bars. After either treatment the Brinell hardness number should not be more than 229.

The steel should be hardened by water-quenching from 780°–800° C., or quenched in oil from 820°–840° C., with a tempering from 130°–180° C. Diamond hardness values between 800 and 900 can be obtained in this way.

The alloy case-hardening steels are covered by specifications En 33, 34, 35, 36, 37, 38, 39. The nickel steels may be either oil or water quenched, according to the core strength desired. The nickel-chromium steels are used to give specially high core strengths. These latter steels are much less susceptible to mass effect when heat-treated than the nickel steels, a matter of some advantage when large sections are treated. Oil-quenching lessens the risk of distortion, so that parts of complex and varying section can be made from them. Double quenching is always better than single quenching for all these case-carburising steels. Typical heat-treatments are given in Table II.

Nitriding steels to En 41B, 40A, 41C, 40C, and 40D are also shown in Table II. Forging of these steels is usually carried out within the temperature range 1050°–1200° C. Hardening is carried out at 870°–900° C., and tempering up to 650° C. Nitriding temperature is 500° C.,

It would not be fair to conclude this article without reference to the splendid work done by the Technical Advisory Committee of the Alloy and Special Steels Committee of the Ministry of Supply. This article has been based on B.S.S. 970 and 971, and is an attempt to simplify the heat-treatments of the more important steels detailed therein.

Welding Research Symposium

USEFUL discussions on the applications of research to industry were a feature of the British Welding Research Association's symposium on the Metallurgy of Steel Welding held at the Waldorf Hotel, London, last week.

The President of the Association, Sir William J. Larke, said that research was useless if the results obtained did not find practical application and thus make their contribution to the improved efficiency of industrial production. It was only through enlightened interest in the work that they could hope to secure support, both personal and financial, from the industries concerned in the development and application of welding.

Undoubtedly one of the most effective means of securing that objective was by the organisation of symposia at which those engaged in research could make authoritative statements on the work and its results, and receive in return comments, suggestions and criticisms which would stimulate further effort and in many cases suggest additional avenues for exploration.

Mr. A. Ramsay Moon, the Director of Research, gave an outline of the Association's work in relation to the metallurgy of steel welding and Mr. J. G. Ball, Secretary of the Main Ferrous Metal (Metallurgical) Committee supplemented Mr. Moon's remarks with an analysis of the various papers submitted at the symposium.

The general conclusion from the discussion was that it was in the interest of research and industry to have a series of symposia and the Research Association are planning along these lines. The papers and discussion will be published in due course by the British Welding Research Association as a volume of Proceedings.

The Nickel Bulletin

THE Nickel Bulletin for October contains abstracts dealing with precipitation-hardening copper alloy powders, creep properties of binary iron alloys, temperatures and emissivities of heat-resisting alloys, and the determination of lead and boron in nickel chromium steels.

Copies of the Nickel Bulletin may be obtained free of charge on application to The Mond Nickel Company, Limited, Grosvenor House, Park Lane, London, W.1.

Alloy Steels in War and Peace

By J. W. Donaldson, D.Sc.

A broad survey of the activities and achievements of British industry in the alloy steel field is given. Brief reference is made to the conditions imposed upon the steel industry during the war and how difficulties were overcome. It is shown that while the general character of steel compositions is not likely to change, new low alloy steels developed for wartime use, because of their special military characteristics or because of shortages of alloying elements, will find new uses. Attention is directed to low alloy steels made from alloy steel scrap and to future trends.

THE year 1945 has seen the end of the world war and the beginning of the change over from war to peace-time conditions. The iron and steel industry, which attained its peak year in production in 1943, continued during the first half of the year to produce steel on a high level for the fighting and defence services, and for the industries essential to war. In the latter half of the year, however, there was a decided falling-off in the production and use of steel for such purposes and a very distinct switching over to the production of steel for post-war conditions. With the relaxing of security conditions the past year has also seen the publication of research and other work carried out during the last six years to meet the demand for steels required for modern warfare, and has shown the difficulties and problems the industry has had to meet. Statistics have also been issued during recent months for the British Iron and Steel Industry by the British Iron and Steel Federation, and have supplied interesting figures relating to all branches of the industry. With the publication of such information it is now possible to review the activities and achievements of the war years and to consider possible future trends with regard to the application of various types of steel.

Alloy Steel Production

In the production of alloy steels, statistics have shown an increase during the last six years. In 1939, steels defined as alloy steels did not exceed about 5% of the total British steel production. During the five years of war to the end of 1944, the average proportion rose to 10% and for the two years 1942 and 1943, it was over 12%. This increased production was made at a time when the iron and steel industry was facing many difficulties regarding raw materials and particularly ferro-alloys. Figures published recently have shown that over 80% of the ferro-alloys used had to be imported

and, although a fairly large proportion of those alloys including those of manganese, chromium, nickel and tungsten, was obtained from Empire sources, great difficulties were found in obtaining the necessary shipping for importing them. Ferro-alloys imported from Norway, Sweden, Greece and the Far East were not available during the latter years and represented a very serious loss. Increased production was also made to a large extent in plants normally used for the making of carbon steels and processed in mills and forges also used for carbon steels, and with all the difficulties for the slower working and more careful handling required for the production of alloy steels.

Alloy Steel Rationalisation

To deal with the shortage of alloying elements brought about by war-time conditions, the well-known War Emergency British Standard Specification 970 was drawn up by the Technical Advisory Committee of the Special and Alloy Steels Committee of the Ministry of Supply and issued in 1941. This Schedule of steel, designated the En steels, originally contained 15 carbon and 43 alloy steels in the form of bars, billets, light forgings and stampings up to a ruling section of 6 in. A revised issue of the specification was made in 1942 and memorandums and amendments were added to it from time to time. The memorandums, three in number, were issued with the object of alloy conservation and defined the number of alloy steels permitted for war purposes. In the last memorandum issued in September 1944, 35 of the original 43 alloy steels were permitted. The non-permitted steels were 3 and 3¼% nickel steel, 3% nickel-chromium and 3% nickel-chromium-molybdenum steels, 3% and 5% nickel-chromium case-hardening steels, 1% and 3% chromium-molybdenum steels and 1% chromium-vanadium spring steel. The alloy steels permitted during the present year are given

TABLE I.—PERMITTED ALLOY STEELS.

B.S.En	Type of Steel
33	3% Nickel case hardening.
34	2% Nickel Molybdenum case hardening.
35	2% Nickel Mo (higher carbon) case hardening.
36	3% Nickel Chromium case hardening.
39	4½% Nickel Chromium case hardening.
40	3% Chromium Molybdenum.
41	1¼% Chromium Aluminium Molybdenum.
48	1% Chromium.
50	Chromium Vanadium.
51	3% Nickel.
52	Silicon chromium.
53	Silicon chromium.
54	Nickel Chromium Tungsten.
55	Chromium Nickel Tungsten.
56	Chromium rust resisting.
56M	Chromium rust resisting (low carbon).
56A	Chromium rust resisting (low carbon).
56AI	Chromium rust resisting (low carbon).
56AM	Chromium rust resisting (low carbon).
57	Chromium Nickel rust resisting (high tensile).
58	Austenitic chrom. nickel rust and acid resisting.
58A	Austenitic chrom. nickel rust and acid resisting.
100	Low Alloy (heat-treated bars for machining).
101	Low Nickel Chromium Molybdenum.

TABLE II.

MECHANICAL PROPERTIES OF SOME ALLOYS USED FOR LIGHT-WEIGHT CONSTRUCTION.

Material and Condition	Specific Gravity	Weight lb. per cu. in.	Yield Point Tons per sq. in.	Ultimate Stress Tons per sq. in.	Elongation % on 2 in.	Modulus of Elasticity Million lb. per sq. in.	Fatigue Strength Tons per sq. in.
Ordinary Structural Steel, 0·2% carbon	7·86	0·284	15·5	27·0	28	30·0	13·5
Low Alloy High Strength Steel, hot rolled	7·87	0·284	25·0	32·0	20	29·0	20·0
Stainless Steel, 17/7, cold rolled	7·9	0·285	72·5	82·5	15	26·0	35·0
Aluminium Alloy, extruded, aged	2·8	0·1	35·0	39·0	10	10·4	10·0
Aluminium Alloy, plate, aged	2·77	0·1	20·0	26·0	19	10·3	7·0
Magnesium Alloy, extruded	1·81	0·065	15·0	20·0	11	6·5	8·5

in Table I, and include constructional and engineering, case hardened and nitriding, valve and spring, and corrosion and heat-resisting steels.

To assist in taking advantage of the alloy content of steel scrap, two new specifications were added to the En series in 1943, one for heat-treated low-alloy steel bars (En 100) and the other for a low nickel-chromium-molybdenum steel (En 110). Specifications were also issued for two carbon-manganese case-hardening steels (En 201 and En 202), one of which was a free-machining steel. Another case-hardening steel, (En 320), containing 1·8 to 2·2% nickel, 1·8 to 2·2% chromium, 0·15 to 0·25% molybdenum and 0·14 to 0·20% carbon, was added at the beginning of this year. The mechanical properties of this steel, which is suitable for high duty parts requiring high tensile core strength, are specified to be, when suitably heat-treated, as not less than 85 tons per sq. in. tensile strength, 12% elongation and 25 ft. lb. minimum Izod impact. With these various additions, permitted alloy steels at the present time number 40.

Although the production figures for alloy steel showed a falling-off in 1945 as compared with 1942 and 1943, alloy steels continued to be used for the same wide variety of purposes, and their application continued during the earlier part of the present year for arms and equipment for all the three Services. Of the permitted steels available the carbon-manganese, the manganese-nickel-molybdenum and the manganese-molybdenum continued to replace the low nickel, the 3% nickel and the 3½% nickel steels. The lower nickel-chromium-molybdenum steels replaced the higher nickel-chromium steels which were non-permitted and the same substitution applied to the alloy case-hardening steels, where 3 and 5% nickel chromium case hardening steels were not available. The most widely used corrosion and heat-resisting steels continued to be the 12% chromium and the 16/2 and 18/8 types. The use of the free-cutting stainless steels also continued to develop in the manufacture of various components for corrosion resistance purposes. Extended use has also been made since their introduction and continue to be made of the low alloy steels En 100 and En 110 made from alloy steel scrap and such steels have replaced the higher alloyed manganese-molybdenum and nickel-chromium-molybdenum steels for many constructional applications.

Post-War Future of Alloy Steels

The advances which have been made during the last five years in the production, treatment and utilisation of the wrought alloy engineering steels will have an important influence with engineers, designers and users of alloy steels in the post-war years. The low alloy steels, the use of which has been necessitated by the need for alloy conservation, have already been responsible for substantial advances in processing, design and fabrication technique. The introduction of the ruling section in the En Schedule was its most important feature for it recognised the influence of mass effect in respect of heat treatment and permitted the desired mechanical properties being obtained by heat treatment in a steel which contained the lowest alloy content possible. This relationship is important economically as well as technically and should be an important factor in the post-war future of such steels.

The En Schedule also played an important part in rationalising steel usage so far as wrought steels, both carbon and alloy in their semi-finished condition, were concerned. Now that the war is over the question

arises as to what is likely to happen when alloying elements are more plentiful and controls are removed. The need for conserving such elements still exists and is likely to continue for some considerable time. When these controls go or are relaxed it seems desirable, however, that the principles on which this schedule was based should be maintained and with certain modifications form the basis of alloy steel metallurgy. The large number of alloy steel specifications in existence before the war were not only wasteful in alloying elements but led to unnecessary confusion between steelmakers and users of steel. It appears possible that the use of low alloy steels in preference to the relatively high alloy steels used in pre-war days will continue in most industries using such steels and will also extend to other industries. Such a procedure will be following a practice adopted by the large firms building motor cars and other road vehicles before the war.

A method of testing steels both carbon and alloy, which has been developed in the United States during recent years and which is of considerable importance in selecting the proper steel for a particular component, is the end-quench hardenability test. Using this test the hardenability of a steel can be computed and the heat-treatment characteristics of a steel as influenced by composition and grain size determined, as well as the mechanical properties in various sections. This new method of testing steels is one by which the behavior of a steel during processing, heat-treatment, fabrication and service can be predicted with some degree of accuracy, and is one which is likely to play a more important part in the selection of alloy steels in the near future.

Future Applications of Alloy Steels

In selecting a steel for many purposes, weight saving without loss of service life is an important factor and is one in which the low-alloy high-tensile steels should fill an important place in new developments. Such steels were developed some ten years ago, several years before war conditions necessitated the conservation of alloying elements and were used in many forms both in railway and road transport, particularly in the United States where their use increased to a considerable extent. Mild alloy steels of lower tensile properties containing copper and copper-molybdenum were also making considerable progress not only in rail and road transport, but also in shipbuilding and other industries where resistance to corrosion by the atmosphere, sea-water and petroleum products was required.

In a recent American Symposium the relative merits of low alloy steels, stainless steels, aluminium and magnesium alloys, were discussed by engineers and designers as materials for light weight construction, and typical values for some of the materials used, taken from a paper presented at the Symposium, are given in Table II. The two types of alloy stainless steels considered most suitable for light weight construction were the 17/7 and 18/8 austenitic steels in the form of cold-worked sheet or strip or cold drawn bars, rods or wires, while the low-alloy high-strength steels included those to which moderate amounts of alloying elements had been added so as to impart, in the hot-rolled condition, a minimum tensile strength of 32 tons per sq. in. and a minimum elongation of 20% on 2 in. With the experience gained from the use of low alloy steels in the United States and in this country during recent years, there is little reason to doubt that a considerable increase will be made in the application of both low-

alloy and low-alloy high-tensile steels and that, as their fabrication is improved, lighter designs at lower costs will result.

Stainless and Heat-Resisting Steels

During the last few years stainless and austenitic heat-resisting steels have been increasingly used not only for corrosion and heat-resisting purposes, but also on account of their higher mechanical properties for light-weight structures, as already instanced. Developments in such steels have been assisted by the wider application of the free-machining varieties ; by improved processing techniques whereby the higher alloyed materials have been rendered capable of fabrication by forging, machining, etc. ; by the nitriding of such steels and by surface treatments such as blackening and electro-polishing. The steels used have tended to fall into three general types :—12 to 14% chromium stainless iron or steel, and the 16/2 and 18/8 chromium-nickel. Smaller quantities of special high alloyed materials have also been used for particular purposes.

A considerable amount of work has also been carried out on the development of steels and alloys with high creep resistance properties and details of such work are now being made available. Developments have also taken place in valve steels for low and high-power aircraft engines. All such steels, both old and new, will no doubt find an important application in future engineering developments particularly for parts in aircraft engines and components, in oil-engine construction, in jet propulsion, in gas turbines and in many parts where a high resistance to corrosion and temperature is required.

Alloy Steel Castings

The production of medium and high tensile steel castings during the early days of the war was called for in order to meet the demand for material for all three Services. Such castings had to take the place of forgings for many parts and in order to meet such requirements many investigations had to be carried out in steel-making and foundry practice, and inspection technique had to be developed and improved. To obtain the strengths required in such castings, alloy steels were used. At first these were of the usual type, but latterly, as a result of alloy conservation, had to be replaced by those of lower alloy content. Alloy steels used for such purposes were carbon-manganese steels containing small amounts of nickel, chromium and molybdenum, manganese-molybdenum steels containing 1·5% manganese and 0·2 to 0·5% molybdenum, chrome-molybdenum steels containing 1·5 to 2·5% chromium and 0·2 to 0·5% molybdenum and 2·5 to 3·5% chromium and 0·5 to 0·75% molybdenum respectively, and nickel-chromium-molybdenum steels containing 2·5% nickel.

As a result of the various investigations and the application of the results obtained to production methods both on melting and moulding, together with the high degree of inspection carried out by X-ray and other methods, cast steels having tensile strength up to 60 tons per sq. in. in 4 in. sections and up to 80 tons per sq. in. in smaller sections were produced, and such strengths were accompanied by good elongation and Izod impact values. Good machining and welding properties were also obtained. Applications for alloy steel castings were for aircraft components, vehicle parts, gear wheels, etc., and such applications were being continued and extended right up to the end of hostilities.

In post-war development, low-alloy steel castings ought to play an important part due to their high tensile strength and to their flexibility for design purposes. The fact that such steels also machine well and can be welded easily, will allow of their use in many industries. A wider use will also be made of high-alloy corrosion and heat-resisting castings in furnace parts and heat-treatment equipment, particularly for alloys requiring a high order of resistance to deformation at high temperatures and where such deformation is brought about by hot-rolling or forging. The manufacture of precision castings in low-alloy and stainless steels by the lost wax process which has been developed during the war, particularly in the United States, also offers certain possibilities for peace-time production.

Alloy Tool Steels

Alloy tool steels consist of carbon tool steels containing relatively small amount of alloy elements and of high-speed tool steels containing large proportions of tungsten with or without cobalt and smaller proportions of chromium and vanadium. The former are either high-carbon steels (1% carbon), containing less than 1·0% of chromium, tungsten or vanadium, or high carbon-chromium (0·5 to 1·5% chromium), low chromium-tungsten (1·0% chromium, 1·5% tungsten), chromium-molybdenum (6% chromium, 1% molybdenum) or nickel-chromium (3·5% nickel, 0·75% chromium) steels, non-distorting on oil or water-hardening. Such steels have had an increasing use for a variety of purposes, including high-quality press tools, gauges and dies, and their use is likely to increase as processing and fabricating techniques for material are developed in the future.

The loss of the main sources of tungsten early in 1942 rendered necessary the conservation of this element and restricted very considerably the use of high-speed steels containing 14, 18 and 22% tungsten for machining. Substitute steels of the American type containing molybdenum, chromium and low tungsten, with small amount of vanadium, were recommended by the Iron and Steel Control to replace the higher tungsten steels which were only allowed to be manufactured and used under licence, when it was proved that substitute steels were not suitable. Although these substitute steels could be handled in a similar manner to that adopted for standard high-speed tool steels, provided certain precautions were taken in their treatment and although they gave fairly satisfactory results in service, there was a quick return to the higher tungsten steels, as restrictions were gradually removed during 1944 and the present year.

The future trend as regards the use of alloy steels for high speed machining will be a return to the pre-war steels as soon as they are available in quantity and the development of new steels for the high speed machining of such materials as hard alloy steels and cast irons. The quantity of such steels produced will probably show a decline as the use of weld tips of high-speed steels becomes more general and due to the increased use of carbide cutting tools.

ERRATA, November 1945 issue

Page 1, 14th line, first paragraph, "ensures" should read "ensure." Page 21, 5th line from top of right hand column "Selryt" should read "Selvyt," and in photomicrograph C, at the bottom of the same page, the arrow and the word steel should be transposed to refer to the bottom of the illustration.

The International Aluminium Cartel

THE announcement that the international aluminium cartel has ceased to function will be received by those directly interested, with mixed feelings, depending upon whether their interests are on the production or consuming sides. Actually the history of the aluminium industry in relation to cartels is repeating itself, because the cartel which has recently ceased to be operative was formed to replace the third international aluminium cartel which was to have terminated, under agreement, on December 31, 1931. The organisation then established at Basle, Switzerland, as a stock company was called the Alliance Aluminium Cie., A.-G. with a capital stock of 35 million Swiss francs.

The first international cartel in the aluminium industry was formed in 1901. Declining prices, poor sales, increasing competition and the unsatisfactory outlook at that time were some of the conditions which impelled the producers of primary metal to establish this organisation. Among other provisions, the cartel agreement stipulated the fixing of minimum prices, allocation of quotas and sales territories, and uniform conditions of delivery and payment. Renewal of the first agreement was effected by the producers in 1906, but late in 1908 the cartel was dissolved.

The price policy of the cartel was severely criticised by consumers and others, especially during the late years of its existence. Claims were then made that the price was immoderately high and the policy extortionate. Obviously, however, price movements of a metal should be compared with those of other metals during the same period, if a fair estimate is to be obtained of the policy adopted. After a careful examination of the price movements of other non-ferrous base metals it will be found that the advance in aluminium prices to the high level of 1907 was not due mainly to cartel policy, but rather to the general economic situation. The price of commodities naturally moved higher with the increasing demand which accompanied the rise in trade and that of aluminium would have advanced without cartel influence.

After the cartel was dissolved, aluminium prices were depressed to low levels in the competition for business. Final collapse of this—the first—international cartel, was due in part to circumstances over which it had no control and in part to situations of its own making; it is extremely doubtful, however, whether a different policy would have preserved the organisation under the complex conditions encountered at that time.

Efforts were made to form a new international cartel in 1910-11, but they failed because producers could not reach agreement concerning quotas and output; certain marketing arrangements, however, were in operation. Eventually, agreement was reached among the principal producers and a new cartel was formed in 1912, which was generally referred to as the International Aluminium Syndicate. This second cartel was similar in type to the first, and the objects of both were the same, although prices were determined by joint agreement of the members. This new cartel functioned until the outbreak of war in 1914, when its activities came to an end.

After 1918, conversations were held among European producers over a period of several years, with a view to forming a new organisation, but agreement could not be reached until 1923, when the first post-war agreement, limited to prices, was effected. This finally led to the formation of a new international organisation in 1926; it was originally established for a period of two years, but the agreement was renewed in 1928 for three more years. Among the objects for which this—the third—cartel was formed are included the following :—To regulate and control the aluminium sales of each of the members, more particularly by the exchange of commercial information in their possession ; to promote, by all means in conjunction with customers, the more widespread use of aluminium ; to supply the customers of every member with the quantities and qualities of metal requisite for his needs ; and to reduce to a minimum general costs and transport costs. Other specific objects included the following :—To increase output, expand exports to non-producing countries, exchange information in respect of technical processes and patents, eliminate competition and the transport of metal as between producing countries, and promote co-operation among outside companies engaged in the production of semi-finished and finished manufactures. The aims of this organisation, therefore, embraced a range beyond that of the usual cartel.

As mentioned earlier this so-called third cartel was to be terminated at the end of 1931, but a few months before a new organisation was formed to replace it— the Alliance Aluminium Cie., which has just been dissolved. The question naturally arises whether arrangements will be made to form another organisation. Although the difficulties of reaching agreement are increasing and the word cartel frequently calls for much abuse, it seems that some form of world planning will be necessary to establish and maintain world trade at a high level. The formation of cartels in general can have undesirable restrictive consequences which should be adequately guarded against, but, whether that or another term is used to apply to international planning arrangements, it seems likely that, as far as the aluminium industry is concerned, history will repeat itself, although the form in which it does may be modified.

Production of Aluminium in Canada

THROUGHOUT 1944 the ore treatment plant of the Aluminium Company of Canada Ltd., located at Arvida, Quebec, was in continuous operation. This plant produces concentrates from which metallic aluminium is recovered. The crude bauxite ore employed in the production of these concentrates is imported. During the past year this company produced primary aluminium ingot at each of its five reduction plants located at Arvida, Shawinigay Falls, La Tuque, Isle Maligne and Beauharnois, all situated in the province of Quebec.

Production of primary ingot in 1944 totalled 924,130,162 pounds compared with the all-time high record of 991,499,296 pounds in 1943. The company has reported that during the five war years ending December, 1944, only 6 per cent. of Canadian production was consumed in Canada, while the United Kingdom was the largest buyer, having consumed approximately 55 per cent. of production. The United States was second with approximately 32 per cent. of the total. Russia took 4·3 per cent., Australia 1·2 per cent. ; other United Nations absorbed the remaining 1·5 per cent.

THE BRITISH ALUMINIUM CO. LTD., Temporary Head Office, Salisbury House, London Wall, London, E.C.2, announce that their telegraphic address has been changed to BRITALUMIN AVE LONDON. Address for cables will be BRITALUMIN LONDON.

Wear Resistant Steel Castings for the Mining Industry

By T. E. Norman

Metallurgical Engineer, Climax Molybdenum Co.

A major portion of the wear resistant parts used by the mining industry is made from steel castings. Most of these wear resistant castings are made from alloy steel either of the austenitic " Hadfield " manganese type or of one of the lower alloy types in which the composition and heat-treatment are specifically designed for the application in question. These low alloy steels have found increasing popularity with the mining industry because of specific advantages which they have over austenitic manganese steel in many applications. Better machinability and wear resistance, high yield strengths, ease of production, desirable magnetic properties and low first cost are a few of the advantages they possess.

The chromium-molybdenum types of low alloy steel have shown outstanding merit in wear resistant castings and a brief summary is given here of certain types of these steels which have been found particularly suited to the needs of the mining industry.

FOR most wear resistant chromium-molybdenum steel castings it is permissible to use a fairly broad range in analysis and heat-treatment. This makes them suitable for production in many of the foundries serving isolated mining districts where conditions are such that it would be difficult for these foundries to meet narrow ranges of chemical analysis or exacting heat-treatment. However, for best results it is desirable to keep the analyses within the ranges specified in this summary. Also, if steel of highest ductility and toughness is required, proper attention should be given to the refining and deoxidation practice used in making each heat of the steel.

The heat-treatments recommended assume that the steel foundries have car bottom heat-treating furnaces to conduct annealing, air cooling (normalising) and tempering operations on the castings.

Recent tests indicate that castings having unusually good combinations of wear resistance and toughness may be produced by liquid quenching in oil or molten salts. However, since relatively few foundries have the equipment necessary for such heat-treatment, this will not be discussed in detail in this summary.

Four specific types of chromium-molybdenum steel for wear resistant castings are discussed. In addition, a chemical range is given from which an analysis for grinding balls may be selected. All the analyses listed can be made in either acid or basic lined electric or open-hearth furnaces. They can also be made in a Bessemer converter if the chromium content of the steel does not exceed about 1·5%; however, higher percentages of chromium can be added as exothermic briquettes.

Machining

Where the amount of machining on a casting is a major consideration and the maximum in wear resistance is not necessary, it may be desirable to select steel of Type 1, since this type can be machined quite readily after all heat-treatment has been completed. If maximum wear resistance is desired Types 2, 3, or 4 should be selected. However, these three types require an anneal prior to rough machining. After rough machining, the castings are normalised and tempered as specified, followed by any finish machining or grinding which may be necessary. High-speed steel, special alloys of the Stellite type, or carbide tipped tools can be used for machining the steels.

Press Straightening or Bending

Castings made from steel of Types 1, 2, or 3 may be press straightened, or bent to a limited extent, after annealing or after being normalised and tempered. For Type 4 steel, however, the practice of press-straightening is not generally recommended.

Welding and Flame Cutting

Generally speaking, steels of medium or high carbon content are difficult to weld due to their tendency to develop cracks in the heat affected zone. Type 1 steel can be welded without any particular difficulty provided the steel is pre-heated and post-heated. If possible, welding should be done before the castings are normalised and tempered.

Castings of Types 2 or 3 steel are difficult to weld properly. If welding must be done on these types the use of austenitic stainless steel rods is recommended. Welding should not be attempted on Type 4 steel.

Flame cutting tends to form small cracks adjacent to the cut on steels of Types 2, 3 or 4. Gates and risers attached to castings should therefore be placed in positions where their removal by flame cutting will have little effect on the quality of the casting even if small cracks are formed below the cut surface. These cracks are generally quite shallow and may be ground out if desired.

Flame cutting around bolt holes or other critical sections of a casting should be strictly avoided, particularly on steel of Types 2, 3 or 4. If such cutting is absolutely necessary to salvage a casting, it can be done safely while the entire casting is at a temperature of not less than 540° C.

Wearing Qualities

Tests indicate that, when wear occurs by the removal of metallic particles from the casting, the rate of wear under any given condition is controlled principally by the microstructure of the steel. The microstructure is in turn determined by the chemical composition, the rate of solidification in the casting and the heat-treatment.

Insofar as chemical composition is concerned the carbon content of the steel is the most important factor affecting wear resistance. In general, the wear resistance of the steel increases as the carbon content is increased

to 1·0%. An increase in carbon content beyond 1·0% will produce variable results in wear resistance. (Higher carbon contents are not recommended because the castings become dangerously brittle.)

The principal function of the alloying elements in wear resisting steels is to modify the dispersion of carbon, thus producing more wear resistant structures. The presence of chromium and molybdenum carbides also probably contributes additional wear resistance.

The wear resistance of steel of any given composition is generally better the higher the hardness. The improved wear resistance which may be obtained either by increasing the carbon content (up to 1·0%) or the hardness is limited by the need for sufficient toughness to avoid breakage.

Magnetic Qualities

Unlike austenitic manganese steel, all the chromium-molybdenum steels listed can be picked up by a magnet and be detected by magnetic detectors. This characteristic alone often makes the chromium-molybdenum steels preferred over austenitic manganese steel for wear resistant parts used to handle coarse ore. Any parts made therefrom which become lost in the ore can be picked up by the tramp iron magnets or detected by a "magnetic eye" before they enter the crushers where they may produce costly breakdowns.

Analyses and Heat-Treatments

(1) Parts Requiring Substantial Ductility and Toughness.

ANALYSES.

	Type 1.	Type 2.	Type 3.
Carbon	0·35 – 0·45%	0·50 – 0·60%	0·45 – 0·55%
Manganese	0·60 – 0·90	0·60 – 0·90	0·50 – 0·70
Silicon	0·80 maximum	0·80 maximum	0·80 maximum
Chromium	0·90 – 1·25	0·90 – 1·25	2·75 – 3·25
Molybdenum	0·20 – 0·20	0·30 – 0·40	0·45 – 0·55
Sulphur	0·04 maximum*	0·04 maximum*	0·04 maximum*
Phosphorus	0·05 maximum*	0·05 maximum*	0·05 maximum*

* The lower the better.

HEAT-TREATMENTS.†

	Type 1.	Type 2.	Type 3.
Heat to	950° C.	950° C.	950° C.
Minimum time at temperature per inch of sections	1½ hr.	1½ hr.	1½ hr.
For light sections cool in	Still air	Still air	Still air
For heavy sections cool in	Moving air	Moving air	Moving air
Temper at‡	560–680° C.	560–680° C.	560–680° C.

Cool after tempering in still air or in the furnace.

† Type 1 can be machined readily after the above treatment. If machining is necessary on Types 2 or 3 it will generally be found desirable to anneal the castings at 980° C. with a slow cool in the furnace down to at least 540° C. Rough machining may then be done and followed by the heat-treatment given above.

‡ The higher the tempering temperature the softer and more ductile is the steel.

(2) Parts Requiring High Wear Resistance with Little Ductility.

The steel described below is designed specifically for use in ball mill liners. However, it can be applied to advantage in a number of other applications where the principal requirement is optimum wear resistance.

ANALYSIS OF TYPE 4.

Carbon	0·80 – 1·10%
Manganese	0·90 – 1·30
Silicon	0·80 maximum
Chromium	2·50 – 3·00
Molybdenum	0·33 – 0·50
Sulphur	0·04 maximum*
Phosphorus	0·05 maximum*

* The lower the better.

HEAT-TREATMENTS.

(a) For mild impact use in the as-cast sand cooled condition.

(b) For relatively severe impact.
Heat to 950° C. to 980° C. and soak at temperature 8 to 10 hrs.
Cool in moving air.
Temper at 430° C. to 480° C. for 5 to 8 hrs.

(c) For severe impact or maximum toughness.
Heat to 950° C. to 980° C. and soak at temperature 8 to 10 hrs.
Cool in moving air.
Temper at 650° C. to 680° C. for 5 to 8 hrs.

Tests indicate that ball mill liners in condition (a) will have a little better wear resistance than liners heat-treated to the same hardness. Most end liners

can be used in the as-cast condition. Shell liners can generally be used in condition (a) or (b) depending on the degree of impact involved.

(3) Grinding Balls.

The use of chromium-molybdenum cast steels for grinding balls represents a new application with very interesting possibilities. Present indications are that balls of this type will have excellent wear resistance and may be produced at reasonable delivered cost from foundries located near the mills. When compared to well made, chilled white iron balls, these cast low-alloy steel balls have shown an increase in life ranging from 40% to 300%. The degree of superiority shown by the cast steel ball depends principally on the character of the material being ground in the ball mill.

The cast steel balls are much more resistant to breakage and spalling than chill cast iron balls. They can, therefore, be used in mills where cast iron balls would be unsuitable.

The range of the analyses used in production of these cast steel balls is approximately as follows :—

Carbon	0·70 – 1·10%
Manganese	0·70 – 1·10
Silicon	0·80 maximum
Chromium	0·50 – 2·00
Molybdenum	0·15 – 0·35
Copper	0·25 – 1·00
Phosphorus	0·07 maximum*
Sulphur	0·05 maximum*

* The lower the better.

It should be noted that the above is not a specified analysis but is a chemical range in which an analysis specification may be selected. The balls are used in the as-cast condition after a controlled cool from the casting temperature. The balls are generally cast in chill moulds on a casting machine.

The analysis selected from the above range and the cooling cycle after casting are inter-dependent factors which are combined to produce balls having the desired microstructure. The most desirable microstructure for these balls will depend to some extent on the degree of impact which they must withstand in the ball mill where they are to be used. It is apparent, therefore, that the cast steel ball analysis best suited for a given foundry will depend on local conditions. These conditions are (1) available cooling equipment (cooling in an air current on a conveyor is desirable) ; (2) the rate and temperature at which the balls leave the casting machine ; (3) predominating diameters of the balls used ; and (4) the microstructures of the steel which will best suit local milling conditions.

Applications

Examples of applications for Type 1 steel are car wheels, couplers and knuckles for mine cars, gears, caterpillar track treads, track rollers and crusher frames.

Typical applications for Type 2 steel are ball mill low discharge grates and lift pans, dipper teeth, mine car wheels, elevator buckets and ball mill scoop lips.

Type 3 steel, which is well suited for castings of heavy section, is especially applicable to roll shells, jaw crusher plates and wearing plates in coarse ore bins.

Applications for Type 4 steel are many, in addition to its use for ball mill liners, are sand and gravel pump runners, pump liners, wear plates, toe lugs on jaw crushers, tyres or wheels for mucking machines, dipper lips on mucking machines and elevator buckets. For these applications heat-treatments (b) or (c) as given for liners are generally used.

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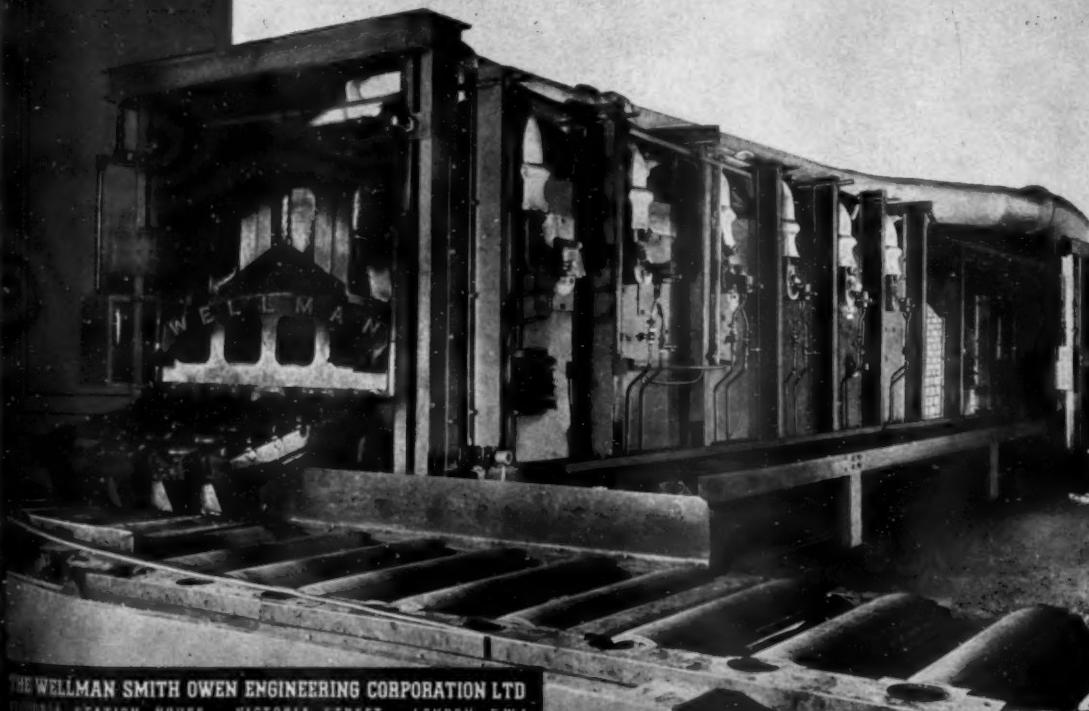
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P. 35.

# Britain's Achievements in Light Metals

Statistics, prepared by the Light Metals Control, illustrate the achievements of Britain's light metals industry during the war period. Quarterly figures from the beginning of 1940 to the middle of 1945, excluding supplies of imported raw and fabricated light metals, show the extent of the achievements made, a brief review of which will be of interest.

IT is justifiable to say that the true evidence of the British light alloys industry's success in satisfying the exacting demands of war is the plain fact of total surrender of the Axis powers. We began war with a relatively small light metals industry. To-day, having achieved victory, we can count among Britain's greatest assets the thriving new industry of tremendous potential power for civilian needs. On the threshold of a new national development for peace-time needs it is a notable landmark in the light alloys industry that the year of victory coincides with the 100th anniversary of the production by Wökler of metallic particles of sufficient size to recognise as aluminium and in sufficient purity to measure some of its properties.

Light alloys of every type are an integral part of aircraft fabrication, and during the war the light alloy industry has seen how productivity can be increased by long-range planning and by the enthusiastic co-operation of management and labour in pursuit of a clear-cut objective. The very efficient factories which have been organised and equipped will now rank as important capital assets in Britain's national economy.

Some idea of the expansion can be gained when it is recalled that in 1936 the total average annual production of magnesium castings was only 400 tons. Yet at one stage of the war, Britain was producing die-cast incendiary bombs at a peak rate of 4,327,000 castings a month. Castings other than bomb castings were produced at the rate of 700 tons a month. If the weight of a bomb casting be taken as 18 oz. the total weight of 4,327,000 castings is about 2,200 tons a month. With other castings this gives a total of 2,900 tons a month, or production peak rate of 34,800 tons a year.

Individual peak achievements in light metals industry, guided by the Ministry of Aircraft Production, in aluminium and magnesium production, and in the fabricating branches of the industry both for aluminium and magnesium, show totals which, even under the stress of wartime urgency are a great credit to the industry and show promise of what can be done to develop light alloys for prefabricated house construction and to satisfy domestic needs of the future.

The peak achievements are summarised in Table I, but the tonnage figures by themselves do not adequately represent the true measure of the effort exerted by all branches of the industry in designing plant extensions, supervising erection, training labour, including a high proportion of female operatives, and in keeping both pre-war and new plants at a high rate of activity in spite of all the difficulties of war-time operation. The figures also take no account of the progressive increase in size and intricacy of the forms of material called for by aircraft and engine manufacturers, and of introduction of higher-strength alloys calling for specialised manufacturing technique.

As will be seen in Table II, many of the totals in aluminium fabrication are difficult even for the technician to appreciate at their true value. At the height of the war effort, for instance, the extrusion branch of

TABLE II.—ALUMINIUM FABRICATION.

LONG TONS.

Period		Sheet and Strip	Foil	Extrusions				Castings				Forgings	Powder	
				Bars and Sections	Tubes	Wire	Total	Sand	Gravity Die	Pressure Die	Total		Granulated (See Note 1)	Flake
1940	I.	*	734	*	*	*	*	*	*	*	*	*	*	*
	II.	11,662	646	6,230	680	532	7,442	*	*	*	7,235	3,155	*	*
	III.	12,861	303	7,223	782	458	8,463	*	*	*	7,356	3,572	*	*
	IV.	14,119	220	6,859	718	372	7,949	*	*	*	7,203	4,338	*	*
	Total	*	1,903	*	*	*	*	*	*	*	*	*	*	*
1941	I.	16,048	150	8,674	865	404	9,943	*	*	*	7,462	5,014	*	*
	II.	14,492	168	8,493	1,002	513	10,008	*	*	*	7,415	4,524	*	*
	III.	13,457	208	10,861	1,101	491	12,453	*	*	*	7,615	4,728	*	*
	IV.	15,942	279	12,186	1,361	579	14,126	*	*	*	9,061	6,581	638	182
	Total	59,939	805	40,214	4,329	1,987	46,530	*	*	*	31,553	20,847	*	*
1942	I.	17,267	336	14,336	1,352	565	16,253	*	*	*	10,145	7,052	930	169
	II.	21,472	482	15,969	1,541	642	18,152	*	*	*	11,357	7,728	733	161
	III.	21,489	415	15,452	1,554	669	17,675	*	*	*	11,568	7,520	802	190
	IV.	24,920	558	20,103	1,707	729	22,539	*	*	*	13,972	9,080	879	201
	Total	85,148	1,791	65860	6,154	2,605	74,619	*	*	*	47,042	31,280	3,344	721
1943	I.	25,519	667	19,786	1,787	804	22,377	*	*	*	14,546	9,961	1,192	236
	II.	25,982	1,024	22,715	1,665	707	25,087	*	*	*	15,087	10,345	1,023	231
	III.	24,666	1,034	21,486	1,883	735	24,104	*	*	*	14,301	11,177	1,160	235
	IV.	27,944	1,102	23,750	1,905	835	26,490	*	*	*	15,499	11,704	1,689	297
	Total	104111	3,827	87,737	7,240	3,081	98,058	*	*	*	59,433	43,187	5,064	999
1944	I.	30,042	1,124	25,170	1,907	934	28,011	9,681	6,048	522	16,251	12,626	2,626	361
	II.	25,817	1,001	15,247	1,400	873	17,520	9,000	5,221	437	14,658	9,874	4,136	331
	III.	20,382	934	13,419	1,118	670	15,207	7,476	4,660	398	12,534	8,637	5,898	308
	IV.	17,344	1,193	13,824	794	592	15,210	6,466	3,973	367	10,806	7,380	7,077	215
	Total	93,585	4,252	67,660	5,219	3,069	75,948	32,623	19,902	1,724	54,249	38,517	19,737	1,215
1945	I.	13,693	1,409	9,419	575	298	10,292	6,000	3,863	340	10,203	4,200	9,007	125
	II.	12,234	1,236	6,464	396	220	7,080	5,801	3,210	325	9,336	2,544	6,158	58

Notes.—(1) Includes only powder for direct military purposes, and excludes powder for industrial purposes.
(2) * Denotes not available.

TABLE I.—PEAK ACHIEVEMENTS.

Description	Monthly Production (tons)		Ratio Peak 2nd Qtr. 1940
	Basis 2nd Qtr. 1940	At Peak	
Virgin Aluminium	1,536	4,882	3·2
Magnesium (including Scrap Recovery)	495	2,294	4·6
Aluminium Sheet and Strip ..	3,887	10,743	2·8
Aluminium Extrusions	2,481	9,840	4·0
Aluminium Castings..	2,412	5,783	2·4
Magnesium Castings (other than bombs)	316	734	2·3
Aluminium Forgings	1,052	4,208	4·0

the industry was producing 9 million light alloy tubes every month and the amazing total of 400 million light alloy rivets every week—representing approximately 660,000 rivets a second over a 24-hour working day.

In the castings branch of the industry the totals are also impressive, but what is of more true value in assessing the work of this firm British craftsmanship is the greater intricacy of castings which could be handled and the training of new semi-skilled labour for these vital tasks.

TABLE III.—MAGNESIUM FABRICATION

| Period | | Sheet (Long Tons) | Extrusions (Long Tons) | Castings | | Forgings (Long Tons) | Powder (Long Tons) (See Note 1.) |
				Other than Bombs (Long Tons)	Incendiary Bombs (Nos. in 1,000's)		
1940	I.	14	*	*	*	*	*
	II.	39	*	949	*	*	*
	III.	38	54	986	*	*	*
	IV.	37	31	946	*	*	*
	Total	128	*		*	*	*
1941	I.	50	20	1,014	81	13	*
	II.	28	40	1,013	515	29	386
	III.	31	51	997	1,328	20	551
	IV.	22	37	973	1,929	40	476
	Total	131	148	3,997	3,851	102	*
1942	I.	30	67	1,060	2,359	32	455
	II.	45	81	1,187	2,783	33	518
	III.	51	58	1,219	5,456	42	396
	IV.	39	79	1,368	5,309	7	248
	Total	165	285	4,834	15,907	114	1,617
1943	I.	29	105	1,288	7,737	3	456
	II.	27	60	1,401	9,395	16	674
	III.	47	49	1,351	9,468	13	919
	IV.	45	79	1,787	11,106	13	904
	Total	148	293	5,927	37,706	45	2,953
1944	I.	43	97	2,000	12,981	15	842
	II.	53	71	1,903	12,022	6	841
	III.	78	57	1,846	10,619	9	683
	IV.	30	49	1,907	4,137	9	796
	Total	204	274	7,656	39,759	39	3,162
1945	I.	15	46	1,735	1,994	5	732
	II.	35	45	1,348	1,464	3	636

Notes.—(1) Includes all grades, pure and alloy.
(2) * Denotes not available.

Not only were many more castings required, but, simultaneously, a very much higher proportion of the large intricate castings in high-strength heat-treated alloys. An acute shortage of skilled foundry labour had also to be overcome by the maximum use of mechanisation and scientific control. This particularly applied to castings for aero engines, in which output rose from approximately 600 tons a month at the middle of 1940, to 2,500 tons a month in early 1944.

Output of cylinder heads for air-cooled aero engines reached a peak of 2,000 heads a day. Production of electrical plugs and sockets for aircraft was increased from 425,000 castings a month at the beginning of 1942, to 3,000,000 in just 12 months.

Magnesium castings for wheels reached a peak of 1,000 a day while the size and intricacy increased progressively during the war period, culminating in the production of the landing wheel for the Lincoln aircraft weighing 336 lb. This is the heaviest single casting produced in either magnesium or aluminium. Table III indicates the progress in fabricating magnesium and its alloys.

Enormous technical progress was made with the production of large gravity die-castings with resultant improved properties, accuracy and greatly increased output for a given labour force and factory space.

Typical examples are cylinder heads and skirts for aero engines, and undercarriage beams for the Lancaster, York and Lincoln aircraft, weighing approximately 125 lb. each.

Production of magnesium bodies for the 4-lb. incendiary bomb increased from 20,000 a month in early 1941, to 4,660,000 at the beginning of 1944, an increase of 230-fold. Over 98,000,000 were produced between 1941 and 1945.

Domestic use of light alloys in the future will benefit from the progress made in light alloy forgings during the war years. The total number of general stampings produced was increased from 1,750,000 a month at the beginning of 1940 to approximately 4,500,000 a month at the beginning of 1944. Output of cylinder barrel forgings for air-cooled radial engines rose to well over 1,100 barrels a day by early 1944. The output of one particular stamping for the Wellington reached a peak of 1,200 a month. Output of propeller blade forgings reached 15,300 a month, while the size and difficulty of the blades required increased progressively during the war period.

Domestic needs and the requirements of the pre-fabricated housing industry are certain to remove any fear that the undoubted expansion of this industry would suffer from an enormous surplus of capacity. Far from prices being depressed it will be realised that this surplus capacity is indeed potential power for rapid reconstruction in housing as well as in many branches of British engineering.

Some Recent Appointments

MR. NOEL KER LINDSAY has been appointed Director of the British Non-Ferrous Metals Federation. Educated at St. Peter's School, York, and Brazennose College, Oxford, Mr. Lindsay was called to the Bar as a member of Gray's Inn in 1927, and practised as a Barrister in London and on the Western Circuit from 1927 until he joined the Army in 1940. He has had a wide experience of commercial and industrial law.

AIR-COMMODORE W. HELMORE, C.B.E., Ph.D., M.Sc., has been appointed Director General of The Aluminium Development Association. Educated at Blundell's School, at the Royal Military Academy and Christ's College, Cambridge, Air-Commodore Helmore served in the R.F.C. in France in the last war and after the formation of the R.A.F. was largely engaged in experimental flying and in aeronautical and scientific research. He has been acting as a technical adviser to the Ministry of Aircraft Production since 1942, having previously been assistant to the scientific adviser to the Chief of the Air Staff from the outbreak of war.

MR. C. F. BATSTONE has been appointed Midland Branch Manager of the British Aluminium Co. Ltd. and has taken up his duties at the Company's Branch Office at 41, Water Street, Birmingham, 3.

Two British metallurgists were invited by the Société des Ingénieurs Civils de France to read papers on metallurgical subjects in Paris on November 9. The first was on " Some Metallographic Work accomplished in Great Britain during the War in respect of Light Alloys " by J. L. Haughton, D.Sc., F.Inst.P., of the National Physical Laboratory, and the second on " Recent Progress in the British Iron and Steel Trade in Great Britain " by D. F. Campbell, M.A., A.R.S.M.

Specifications for Aluminium and its Alloys

Rationalised Schedule Reviewed

Services Schedule, B.S/STA 7, prepared with the object of rationalising the whole field of non-ferrous metals and alloys, has been issued in several sections. The first section dealing with copper and its alloys was reviewed in METALLURGIA in September 1943, the section dealing with nickel and its alloys was reviewed in the issue for April 1944, and the sections dealing with the lead, tin and zinc alloys were dealt with in METALLURGIA for August 1944. The section now reviewed comprises an up-to-date, rationalised schedule for aluminium and its alloys.

THE successful application of aluminium and its alloys to the manufacture of engineering parts by the designer involves full recognition of the specialised technique involved in their fabrication and the characteristic properties associated with this class of materials. The strength of pure aluminium may be increased by alloying or by cold work, and the strength of certain cast aluminium alloys may be still further improved by heat-treatment, while in the case of wrought alloys, this improvement can be achieved either by cold work, by heat-treatment where the composition is suitable, or by a combination of the two forms of treatment. For the purpose of rationalisation, aluminium and its alloys are dealt with in three series : 1. Aluminium—A Series ; 2. Cast Aluminium Alloys—AC Series, and 3. Wrought Aluminium Alloys—AW Series. In the last two series where the term heat-treatment is used, a process is employed involving heating, whereby improvement in the strength of the material is obtained and does not apply to heating with the object of softening or annealing for forming purposes, or to heating for stress relieving for the attainment of dimensional stability, etc.

Pure Aluminium

In the Aluminium Series four materials are scheduled. A1 is 99·99% aluminium sheet, suitable for use where corrosion resistance is of paramount importance, such as under marine conditions for such parts as searchlight and other reflectors. The purity of the metal together with a special form of anodic treatment, enables the maximum reflectivity to be obtained ; 99·8% and 99·6% aluminium sheet are designated A2 and A3 respectively. Both are also suitable where corrosion resistance is important. The first may be used for reflectors, for chemical plant or where exceptional ductility is required, such as components fabricated by impact extrusion, and the second for similar applications except reflectors and also for electrical conductors. A4, 99% aluminium in the form of ingots, bars, tube sheet, wire, and rivets resists corrosion well and is suitable for low strength applications such as halloware, panelling, food containers, mouldings, etc., where ductility is required. This material is also suitable for cold forming and fusion or spot welding.

Cast Alloys

The cast aluminium alloys scheduled in the AC Series, consist of fifteen alloys. Seven of these are casting alloys for general purposes, four are casting alloys for particular applications and four are piston alloys. In Table 1 are given the seven alloys used for general purposes. AC 1, which has good machining characteristics, is suitable for parts subjected to low

TABLE I.—CASTING ALLOY FOR GENERAL PURPOSES—AC. SERIES.

| No. | Description | Composition | | | | | | | | Condition | 0·1% Proof Stress Tons per sq. in. | | Ultimate Tensile Strength Tons per sq. in. | | Elongation % on 2 in. | | Related Specifications |
		Cu	Mg	Fe	Si	Mn	Ni	Zn	Other Elements		Sand Cast	Chill Cast	Sand Cast	Chill Cast	Sand Cast	Chill Cast	
AC 1	Gravity Die Castings	6 to 8	0·1	1·0	2 to 4	—	—	2 to 4	Ni Sn Pb Mn } Total 1·0	As cast	—	—	8	10	—	—	D.T.D. 428
AC 2	Pressure Die Castings	0·75 to 2·5	0·3	1·0	9·0 to 11·5	0·5	1·5	1·2	Ni Cu } Total 3·0	As cast	—	—	8	—	—	—	L.A.C. 112 A.
AC 3	Sand Castings	2·5 to 4·5	0·1	1·0	1·3	0·5	0·5	9 to 13	Ni Sn Pb Mn } Total 1·0	As cast	—	—	9	—	—	—	L.A.C. 113 B.
AC 4	Sand, Gravity and Pressure Die Castings	2 to 4	0·15	0·8	3 to 6	0·3 to 0·7	0·35	0·5	Ti 0·2 Mn } Total Fe } 1·3	As cast	4	4·5	9	10	2	2	D.T.D. 424
AC 5	Sand and Gravity Die Castings	—	3 to 6	0·6	0·25 to 0·75	—	—	Total 1·0 Incl. Fe	As cast	5	5	9	11	3	5	D.T.D. 165
AC 6	Sand, Gravity and Pressure Die Castings	0·1	—	0·6	10 to 13	0·5	0·10	0·10	Ti 0·2 Sn 0·04 Pb 0·05	As cast	3·5	4·5	10·5	12·0	5	7	2 L 33
AC 7	Sand and Gravity Die Castings	0·8 to 2·0	0·05 to 0·2	0·25 to 1·4	0·75 to 2·8	—	0·8 to 1·75	0·10	Ti Ce Cb } 0·05 to Cr } 0·30 Sn 0·04 Pb 0·05	Artificially Aged	7	8	10·5	12·5	2	3	D.T.D. 133 C. D.T.D. 287

stress where ductility or shock resistance is not of first importance, such as miscellaneous vehicle castings and components of electrical equipment, and AC 3 and AC 4 are used for similar applications and properties. AC 4 is also recommended for parts required to be leak proof, such as pump bodies. AC 5 and AC 6 are alloys suitable for use where corrosion resistance is of paramount importance, such as under marine conditions. The former alloy has good shock resistance and ductility and is used for moderately stressed marine craft fittings and for parts which require a good clear anodic finish or a high polish, while the latter alloy possesses exceptional fluidity in casting and is therefore particularly suitable for parts involving thin sections such as casings, covers, etc. It is also suitable for chemical and food plant on account of its good corrosion resistance and for fittings and equipment where ductility and higher impact strength are required. Alloy AC 2 is a useful substitute for AC 6 in cases where secondary composition and lower ductility are acceptable. Good ductility and mechanical properties, which are developed by a low temperature heat-treatment are obtained from AC 7 which is particularly suitable for complicated stressed castings, required to operate at raised temperatures, such as crank-cases cylinder blocks, etc.

Casting alloys for particular applications include two sand and gravity die cast silicon-magnesium alloys, AC 8 and AC 9; a 10% magnesium and a 4 to 5% copper sand and gravity die casting alloys, AC 10 and AC 11. The first three alloys are all suitable for use where corrosion resistance is of importance. AC 8, which contains 4·5 to 6·0% silicon, 0·3 to 0·8% magnesium and 0·25 to 0·8% manganese, has good fluidity in casting and should only be used for particular applications. Small castings are generally supplied in the solution heat-treated condition and large castings are given a special heat-treatment consisting of 4 to 6 hours at 250° C. and then air cooled. AC 9 which is suitable for general purposes, may be subjected to a low temperature heat-treatment to develop a medium strength or to a double heat-treatment to develop a high strength. Alloys AC 10 and AC 11 require

specialised foundry technique. The former, when given a high temperature solution heat-treatment, is suitable for parts requiring high strength with ductility and shock resistance, such as oscillating levers and stressed brackets, and the latter, whose strength and ductility vary according to the heat-treatment given, for such components as brackets and gear cases.

The four piston alloys, which can all be sand or gravity die cast, contain respectively AC 12, 9·0 to 10·5% copper, 0·15 to 0·35% magnesium, 0·3 to 1·0% iron; AC 13, 12 to 14% silicon, 0·5 to 1·3% copper, 1 to 2·5% nickel, 0·75 to 1·5% magnesium; AC 14, 3·5 to 4·5% copper, 1·8 to 2·3% nickel, 1·2 to 1·7% magnesium; and AC 15, 1·3 to 3·0% copper, 0·5 to 1·7% magnesium, 2·0% silicon, 0·5 to 2·0% nickel, 0·8 to 1·4% iron. The first alloy is a heat-treated alloy suitable for pistons for all internal combustion engines, except Diesel and high performance petrol types, and the second a heat-treatable alloy suitable for pistons for high performance engines. The latter alloy has a low thermal expansion and is particularly suitable for anodised pistons and for other applications subjected to high temperature in service such as cylinder heads. AC 14 and AC 15 are also heat-treatable alloys suitable for pistons for high performance engines and for cylinder heads, etc., subjected to high temperatures.

Wrought Alloys

There are two main categories of wrought aluminium alloys: (1) the work hardened or non-heat-treatable alloys which obtain their strength by cold reduction such as rolling, drawing, etc., and (2) the heat-treatable alloys which require treatment at elevated temperatures and of which there are two sub-groups, the single and double heat-treatment types. The strength of alloys in the first category is not normally increased by heat-treatment and as with other metals the annealed condition is the weakest and most ductile, while increase in strength is obtained with increase in cold work at the expense of ductility. Variations of strength in such alloys are obtained for different tempers.

TABLE II.—THREE WROUGHT ALUMINIUM ALLOYS OF THE AW SERIES.

No.	Description	Composition								Condition	0·1% Proof Stress Tons per sq. in.	Ultimate Tensile Stress Tons per sq. in.	Elongation % on 2 in.	Related Specifications
		Cu	Mg	Fe	Si	Mn	Ni	Zn	Other Elements					
AW 10	A. Bars and Sections B. Bar, Sections and Forgings C. Tubes D. Sheet and Strip E. Sheet and Strip F. Wire, Welding Rod and Rivets	—	0·5 to 1·25	0·6	0·75 to 1·3	1·0	—	—	—	Solution Heat-Treated Fully Heat-Treated Fully Heat-Treated Solution Heat-Treated Fully Heat-Treated Solution Heat-Treated	7 15 17 7 15 —	12 18 20 14 20 13	18 10 10 15 8 —	— — — — — —
AW 14	Wire and Rivets	3·5 to 4·5	0·4 to 0·9	0·7	0·7	0·4 to 0·7	0·25	0·10	Ti 0·3 Sn 0·04 Pb 0·05	Solution Heat-Treated	—	25	—	2 L. 37
AW 15	A. Bars, Sections and Forgings	3·5 to 4·8	1·0	1·0	1·5	1·2	0·25	0·10	Ti 0·3 Sn 0·04 Pb 0·05	Solution Heat-Treated ½ in. and under Over ½—3 in. Over 3—6 in. Over 6—8 in.	14 15 12 10·5	24 25 22 20	15 15 12 8	2 L·1 2 L·39
	B. Bars, Sections and Forgings									Fully Heat-Treated ½ in. and under Over ½—1 in. Over 1 in.	24 26 28	28 30 32	8 8 8	D.T.D. 364 A
	C. Tubes D. Tubes E. Sheet and Strip F. Sheet and Strip G. Aluminium Coated Sheet and Strip H. Aluminium Coated Sheet and Strip								(Coating Al 99·5 Min)	Solution Heat-Treated Fully Heat-Treated Solution Heat-Treated Fully Heat-Treated Solution Heat-Treated Fully Heat-Treated	18 23 15 23 15 21	26 29 25 28 25 27	8-12·5 8-12 15 8 15 8	5 T. 4 D.T.D. 461 D.T.D605A D.T.D646A D.T.D610A D.T.D. 390 D.T.D546A

The single heat-treatment alloys in the second category attain their full strength after solution heat-treatment and spontaneous or natural ageing for 4 to 5 days at room temperature. The treatment involves heating to a temperature in the region of 500° C., depending on the alloy, and quenching rapidly in water at 10 to 70° C. The double heat-treatment alloys, while ageing spontaneously to some extent at room temperature after solution heat-treatment, only attain their maximum strength after receiving precipitation heat-treatment or artificial ageing, which involves heating to approximately 165° C. for some hours and cooling in air.

The wrought aluminium alloys scheduled in the AW Series consist of eight non-heat-treatable alloys and ten heat-treated alloys. Alloy AW 1 is a 5% silicon alloy welding wire used for gas and arc welding rods for welding aluminium alloys, particularly of the heat-treated type, where the hot shortness of the parent metal, if used as filler rod, may give rise to cooling cracks. AW 2, a 9 to 14% silicon alloy in the form of bars, sheet, wire and rivets, is suitable for low to medium strength applications according to the temper. The softer tempers have good ductility. The 1 to 1·5% manganese alloy, AW 3, has similar applications to 99·9% aluminium (A4) in the form of sheet or strip, but may be used in the form of lighter gauge sheets, while the 2% magnesium alloy, AW 4, is used for low and medium strength applications in the form of bars, tubes, and sheet for such parts as skins, pressings, floors, fuel pipes and handrails.

Alloys AW 5 and AW 6, containing 3·5% and 5% of magnesium respectively are suitable for use where corrosion resistance is of paramount importance. The first alloy in the form of bars, tubes, and sheets, has medium strength applications as for AW 4 but calling for somewhat higher strength. It can be spot welded, arc welded, and, with some experience, gas welded. The second alloy has also similar characteristics and applications to AW 4, but may be used for moderately stressed parts in the half hard temper, or after cold working the soft material. Rivets in this alloy are normally driven cold, as received, and are used where medium strength is required. AW 7, a 7% magnesium alloy, which is used for particular applications only where medium or high strength is required, is suitable for spot welding but is not recommended for fusion welding except by highly skilled operators. AW 8, containing 2·5 to 4·0% copper, 0·5 to 0·75% magnesium, 0·3 to 1·0% antimony and 0·1 to 0·5% tin, is a free-cutting alloy suitable for use on automatic machines.

Of the ten wrought heat-treated alloys, treatment and the properties for three of which, A 10, A 14, and A 15, are given in Table II, AW 9, a low magnesium-silicon alloy is supplied in the solution heat-treated condition for low strength applications requiring maximum ductility, and in the fully heat-treated condition for medium strength applications. This alloy, which can be welded, is specially suitable for thin sections. The magnesium-silicon alloy, AW 10, supplied in the form of bars, forgings, tubes, sheet, wire and rivets has good corrosion resistance and can be used for medium to high strength applications, and is suitable for welding. If annealed or solution heat-treated, it has very good forming properties with the advantage that heat-treatment after welding will largely restore the mechanical properties. It is suitable for structural parts such as rails, mouldings, etc.

The three alloys, AW 11, AW 12 and AW 13 are supplied in the form of bars, forgings, and wire and rivets respectively. The first is an alloy containing 2% copper, 0·5 to 1·25% magnesium and 0·75 to 1·25% silicon, and is supplied in two tempers, one for medium strength applications requiring some ductility and the other for high strength applications. AW 13 is also a copper-magnesium-silicon alloy containing 1·5 to 3%, 0·25 to 0·5%, and 0·7% of these elements. Rivets in this alloy suitable for medium strength applications are supplied in the solution heat-treated condition and air driven cold. The copper-magnesium-silicon-nickel-iron alloy, AW 12, when fully heat-treated, is used for forgings for high temperature applications. Its machining qualities are good.

The approximate composition, treatment and mechanical properties of AW 14 and AW 15 are given in Table 2. Rivets of AW 14 are supplied headed from soft wire and must be solution heat-heated and quenched immediately prior to driving (within 2 hours) unless natural ageing is delayed by refrigeration. All forms of alloy AW 15 are supplied either solution heat-treated and aged at room temperature for high strength applications or fully heat-treated where the highest strength is required. This alloy is suitable for high stressed structures of all types, but where corrosive conditions are severe, the solution heat-treated condition should be chosen for preference and suitable protection provided such as anodising, painting, etc. In the case of sheet, the aluminium coated form in either condition of heat-treatment can be used where good corrosion resistance is required. Its machining properties are good in both tempers and moderately severe forming, such as bending, flanging, etc., can be undertaken in the solution heat-treated condition.

The alloy containing 3% copper, 4 to 8% zinc, 4% magnesium and 1% manganese, AW 16, is' used in the form of bars and sheet for particular applications only, as are the copper-magnesium-nickel alloys, AW 17 and AW 18, containing 3·5 to 4·5% copper, 1·2 to 1·7% magnesium and 1·8 to 2·3 nickel; and 1·5 to 3·0% copper, 1·2 to 1·8% magnesium, and 0·5 to 1·5% nickel respectively, and supplied in the form of forgings. These two latter alloys are normally used in the fully heat-treated condition for applications requiring high strength at elevated temperatures such as pistons, cylinder heads, etc.

British Industry and Commerce

A SELECT bibliography of literature dealing with the history and reconstruction of British industry and commerce has been published by the Sheffield City Libraries. As Lord Riverdale states in an introduction : The total mobilisation of our national life for war purposes has caused us to face two great tasks—to create a society free from some of the graver weaknesses of the pre-war years, and to reconstruct our economic life in order to make that society possible.

In recognising the need for a guide to the study of these subjects, the Sheffield City Libraries follow a tradition built up by many years of timely and intelligent service to the industries of Sheffield and district. As with previous bibliographies published by this organisation the information given has a much wider usefulness and interested readers are advised to obtain a copy of this booklet from Sheffield City Libraries, Administration Dept., Central Library, Sheffield, 1.

Soviet Metallurgists Tackle New Tasks

By P. Korobov

Deputy People's Commissar, U.S.S.R. Iron and Steel Industry.

THE latest available production figures indicate appreciable progress in the iron and steel industry of the U.S.S.R. Production of peace-time grades of steel and of semi-finished steel products has increased. In comparison with production level of October last year, the level of October this year shows the following increases :—

Pig iron	111%
Steel	110·3%
Coke	113·9%
Ore	123·5%

This increase was carried out under difficult conditions. The reconversion from war-time production to peace-time needs demanded a considerable change in the set-up of the entire ferrous metallurgical economy, with all its complexities and ramifications. During the war, our executives and workers had one main consumer—the front. Technology, planning, organisation, everything, was subordinated to supplying the needs of the Forces. Now transport, including rolling stock and locomotive construction, motor-cars and lorries ; the oil and coal industries ; machine construction ; and especially structural work are making increasing demands on the industry. And it is our task to meet these demands as smoothly and as efficiently as possible.

The U.S.S.R. iron and steel industry entered the post-war period with considerable forces, especially in the eastern regions where the productive possibilities are of a high order. Against this, however, is the devastation caused by the Germans in the southern regions which the iron and steel workers in these regions are making great efforts to restore. As many as 19 blast-furnaces, 53 open-hearth furnaces, 2 Bessemer converters, 38 rolling mills and 59 coking batteries were rehabilitated by November, 1945. The plants, mines and quarries are turning out daily, thousands of tons of ore, fluxes, coke, pig-iron, steel, as well as rolled sections, such as rails, beams and girders, sheets and plates.

Coal mines, machine builders and power workers are making similar headway in rehabilitation, in their respective fields, thus creating the basis for further restoration of blast-furnaces and steel-making units and rolling mills.

We are preparing to enlarge the pre-war assortment of products which calls for all grades of ferrous metals, including low-alloyed steels, with higher strength properties, for the various kinds of machine-building, and in particular, for rolling stock manufacture. Although the peace-time range of steel products is being increased particular attention is being given to the pressing needs of rail transport. All pre-war centres of rail production are being rehabilitated ; the Yenakievo plant in the Donbas is already manufacturing rails. The powerful rail mill of the Stalin combine in Kuznetsk also has begun to turn out its basic products. The restoration of rail mills in Dniepropetrovsk and Dnieprodzerzhinsk is under way. In addition, a new modern powerful rail mill is being installed at the Azovstal works.

During the output competition which preceded the November holidays, many iron and steel plants exceeded their production plans. Leading this drive the workers of the Kuznetsk plant exceeded their planned production for October by 1·3%, in the output of pig-iron by 7%, in the manufacture of steel and by 4·2% in plates and rolled sections. Workers of the Stalin combine in Kuznetsk beat all their previous records in steel output.

Technical advancement, increased range of products, rehabilitation and construction of new shops and plants do not exhaust the tasks facing the metallurgists. The working and living conditions of their men are receiving close attention. At the Magnitogorsk and Kuznetsk works, two of the largest plants of their kind in the Soviet Union, the everyday needs of the worker and engineer are receiving serious attention. Food rations for the workers there have been increased and housing has made a marked advance.

The Geology and Mineral Resources of The Gold Coast

By Dr. N. R. JUNNER, O.B.E., M.C., D.Sc., M.Inst.M.M.
Director of Geological Survey, Gold Coast.

IN this, the second of the Imperial Institute's series of lectures on the mineral resources of the Colonies, Dr. Junner gave a brief account of the geology of the Gold Coast with special emphasis on its mineral resources. The Gold Coast is the world's second largest producer of diamonds (by weight) and the third largest producer of manganese ore ; it has also the largest output of gold of any country in the Colonial Empire.

The Geological Survey discovered the principal deposits of manganese ore, and bauxite, and made many of the first discoveries of diamonds. Commercial development of manganese ore and diamonds commenced in 1916 and 1920 respectively, and bauxite, it was disclosed, in 1940. The average annual value of the mineral production of the Gold Coast had grown from £38,000 at the beginning of the century to £9,160,000 in 1941-42, excluding the value of the bauxite. The total value of the mineral production from 1880 to March 31, 1945, was approximately £120,000,000, of which gold accounted for £90,000,000. The Ashanti Goldfields Mine is the richest large gold mine in the world and Nsuta is the largest single manganese mine in the world. Expenditure on the Geological Survey since its formation had averaged £7,600 p.a., yet the total direct revenue received by the Government in the form of export duties on manganese ore and diamonds alone was nearly three times the total cost of the Geological Survey since 1913 (£225,000), and in recent years it had been about five times the annual cost of the Survey.

In conclusion, Dr. Junner paid a tribute to the valuable work carried out for the Colonial Geological Surveys in general, and for the Gold Coast Survey in particular, by the specialist staff of the Mineral Resources Department of the Imperial Institute during the past 30 to 40 years. The results of the investigations of that Department had undoubtedly played an important part in the appraisal and development of the mineral resources of the Empire.

British Non-Ferrous Metals Research Association

Twenty-five Years of Service

THE annual luncheon of the above Association, held on November 21, 1945, at the Savoy Hotel, London, was more interesting than usual since it commemorated the 25th anniversary of the Association's service to the non-ferrous metals industry as a co-operative research institution and metallurgical centre. The last time this Association met for luncheon was in 1939, but the attendance on the present occasion was comparable with pre-war standards and among the guests were the Lord President of the Council, Mr. Herbert Morrison, P.C., and the President of the Board of Trade, Sir Stafford Cripps, P.C.

In proposing the toast "The Research Association," Mr. Herbert Morrison referred especially to the work of the Association during war and said that its contribution to the war effort and to final victory was an important one and carried out under great difficulties. During the 1914-1918 war, our warships had to spend a considerable proportion of their time in port undergoing repairs and much of that time was spent in fitting new condenser tubes. Corrosion of condenser tubes was a nightmare to the Admiralty. The laboratories of this Association developed and improved cupro-nickel tubing and a cheaper aluminium-brass alloy which became standard materials from which condenser tubes for marine engines are made. In 1940 and 1941, when we of the Commonwealth and Empire were fighting the recent war alone, the Royal Navy was desperately short of ships; these tubes enabled the Navy to keep a high proportion of warships at sea practically continuously and were a notable contribution to the winning of the battle of the Atlantic.

Another development by the Association, to which Mr. Morrison referred, was the L-Delay. This completely novel delayed-action fuse was used on every front in the war from 1941 onwards. The principle of its working is the stretching of a lead alloy by spring-loading until it breaks. In the hands of the resistance movements in Europe, L-Delay was used for detonating explosive charges and gave the Germans considerable trouble. There were other picturesque successes, but there was also the long and patient research, routine and liaison work without which results could not have been obtained and which formed the basis for useful development in many sections of the non-ferrous metals industries.

Continuing, Mr. Morrison said that although the Non-Ferrous Metals Control of the Ministry of Supply had its own technical staff for works' problems, production difficulties, examination of defects in semi-manufactures and components, and problems concerned with the conservation of metals, they relied on the British Non-Ferrous Metals Research Association for almost all background laboratory investigations concerned. The Association carried out several complete research investigations for the Ministry, often in conjunction with producers of raw material and semi-manufactures, the results of which were applied by the Control. To mention only a few of these successes there was the valuable work on solder in relation to tin conservation;

impurities in lower grade copper which had to be used in pursuing ammunition programmes; laboratory work in micro-graphic examinations in connection with the banding of shells; and much technical advice on abstracts of information from technical journals.

In conclusion, he said the British Non-Ferrous Metals Research Association has shown what it can do both in peace and in war. Now is the time when our Research Associations must take an increasingly important part in industry. You will have heard of the financial help that the Government is giving in a variety of ways and it is to be hoped that some of the money now available for ploughing back to industry will be made available by your member firms to the British Non-Ferrous Metals Research Association.

Lieut.-Col. Sir John Greenly who presided, in responding to the toast, expressed his personal thanks, both to the Lord President and to the President of the Board of Trade, for their kindness in having accepted our invitation to this 25th Anniversary. We know he said, that both these Ministers are heavily engaged in great affairs of State, some of which appear to be somewhat controversial, and in consequence, we appreciate all the more this kindness in coming here to-day.

Sir John paid a special tribute to Mr. Thomas Bolton who may be regarded as the founder and father of the Association and to whose foresight and enthusiasm the Association owes a great debt. Next to Mr. Bolton, said Sir John, we owe our greatest debt of gratitude to our two past Directors—Dr. Hutton and Dr. Moore. We are fortunate in having as our present Director, Mr. Bailey, who is filling the position vacated by Dr. Moore with ability and distinction. Under his able management, I am sure the Association will continue to flourish.

Referring to the financial position, Sir John said the future of the Association is the thing that really matters. The Government have pledged themselves to the support of co-operative research. Industry has realised the importance of research and as the President of the Board of Trade will agree, it is specially important to the export trade. Support from industry in a generous measure is essential and the future operations of the Association have been carefully considered by the Future Policy and Progress Committee appointed by the Council in 1943. After full discussion and many meetings that Committee has arrived unanimously at the view that the target to be put before our members should be £70,000 per annum grant-earning income, which Government grant we hope would bring up to at least £100,000. This increased expenditure is aimed at not only to increase the amount of work done but to enable the Association to build up an organisation adequately staffed and equipped to handle the wide variety of problems in the non-ferrous field. We must bear in mind that 1946 is an important year during which we must negotiate new conditions of grant with the D.S.I.R. for the next quinquennium . . . If we are going to get favourable conditions we must build

up our income before the end of 1946 and I hope and believe that the members of the Association will not be found to be lacking in enthusiasm or in faith as to the Association's future.

Mr. H. W. Clarke, member of Council of the Association and first President of the British Non-Ferrous Metals Federation, proposed the toast of "The Guests." Of the many distinguished guests present, he referred particularly to Dr. Hutton and Dr. Moore as being responsible in a great measure for the success of the Association. The only other name he mentioned, and with which he coupled the toast, was the Rt. Hon. Sir Stafford Cripps, the President of the Board of Trade.

Speaking of him, Mr. Clarke said that when Sir Stafford was Minister of Aircraft Production, I was fortunate to have first-hand experience of him. I was one of his Directors on the Light Metals Control, and I must say he inspired us all with his sense of fairness and his ability to support us against the many insidious attacks to which we were subject. In the particular post he now occupies, he is responsible for the trade and industry of the country and although some of us at times might feel that his education has been sadly neglected in certain directions, yet we are all agreed that he is with us in his endeavours to put industry on a sound foundation both scientifically and commercially. He not only wants us to make the best materials metallurgically and mechanically, but he wants us to put those materials on the market in an attractive form so that they will appeal to buyers all over the world. His presence here to-day leads us to hope that H.M. Government are determined to use every effort to further the objects of our Association.

Sir Stafford Cripps in responding, said, I had the advantage myself of being a research worker in my earlier days, and I appreciate very much what Mr. Clarke has said about the shortage of research workers at the present time. We were very remiss as a country in the past in not having nearly sufficient of that type of education which is essential for training up a class of people we require as the basis for our industry to-day, that is the technically and scientifically trained person capable both of research work and of taking up scientific technical posts in industry ... I hope, we shall do everything we can to stimulate the flow of knowledge and of research in order that we might magnify these great invisible exports upon which we can rely so much in the future. Research is not a hobby ; it is not something that you put forward as an advertisement for good business. It is something to be used, and used by every member of a research association. But then one finds that some members of a research association, though keen on research, do not make full use in their own businesses of work that has been done by research associations. I feel sure that we have to see in the future that the results of research penetrate more deeply and widely throughout the whole area of our industrial life.

In the competition that lies ahead of us we must use this weapon in order to win markets in the world with the most valuable products of research. During the war we made full use of research, and I think we can say as a country we excelled every other country in the world in scientific attainment in the war effort. That is what we have to do in the future fight for trade, but that can only be done if every member of the association looks upon it as a responsibility to see that the knowledge

won by a research association is carried right into the production processes in his own business.

I am sure if that is done members will realise that this infinitesimally small percentage on turnover which they are at present devoting to research has got to be seriously increased, in order that their businesses may get the benefit of the knowledge essential to their success.

Following the luncheon transport facilities were available for those desiring to visit the Laboratories in Euston Street. Despite a heavy fog which enveloped London, about 350 visitors took advantage of this opportunity, which indicated more than ordinary interest in the work of this Association. The desire to establish the Association on a larger scale is reflected in a recent report of a special committee set up to consider its future policy and progress. An annual income in the neighbourhood of £100,000 is envisaged, and, if the enthusiasm displayed at this luncheon can be taken as a guide, there should be no difficulty in raising the income to the desired level.

Germany's Steel Tube Industry

As a result of a recent visit to inspect Germany's steel tube plant, Lieut.-Col. S. M. Tate, Assistant Managing Director of the Tube Investments Group, was able to make comparisons with plants in operation in 1938 when he visited similar German plants. His conclusions are that few wartime developments have been made in the steel tube section of the heavy engineering industry in Germany. On the metallurgical side, there were many signs of improvisations to meet shortage of certain materials, but the manufacturing processes themselves had not been changed, and there did not appear to be any evidence of solid metallurgical advance. Taking into account the tremendous destruction of Germany, together with the healthy condition of the steel tube industry in this country, the end of the war finds the British industry in a much better position than the German.

This somewhat surprising lack of development in Germany may be due to any or all of the following circumstances :— the national pre-occupation in the development of terror weapons, the availability of manufacturing capacity for home and war demands as a result of the cessation of exports, and the loss which German industry must have suffered by the fact that so many of her scientists and engineers were compelled to seek refuge in other countries or were put into concentration camps as a result of political purges.

The position is that, for the time being, Germany, by the work of the R.A.F., is denied the use of a number of her works, but the plant and machinery is not seriously damaged, the destruction being chiefly to buildings. If Germany is allowed to reconstruct the damaged buildings, the plants could very rapidly be re-conditioned; and, given the necessary supplies of fuel and power, she could soon achieve her former production level, simply because she had so many plants before the war. Presumably, if Germany is permitted to rebuild her factories, she will do so on more modern lines, and, unless her production potential is rigidly controlled, she could take a lion's share of the European market, where Col. Tate feels that great opportunities for extending British export trade should exist for a number of years.

The late Mr. James Henderson, J.P.

R EADERS will have read with deep regret the announcement of the death, on November 20, of Mr. James Henderson, J.P. whose retirement from his directorship of The United Steel Companies had taken place just a few days earlier.

Born in Glasgow in 1868, Mr. Henderson was educated at Hutchinson's Grammar School and later at Allen Glen's School and the West of Scotland Technical College. His first appointment was in the laboratory of the Glasgow Iron and Steel Co. Ltd. at Wishaw. He became associated with Mr. Mannaberg in that Company and commenced to operate the Bessemer process under the supervision of Mr. Mannaberg. This association with Mr. Mannaberg was renewed in 1889, when Mr. Henderson moved to Frodingham in North Lincolnshire, where the basic open-hearth process was being developed and where he remained for the rest of his active business life.

Joining the Frodingham Company as works chemist, he became Joint Managing Director in 1908 and Director and General Manager in 1916. When the Frodingham Company was purchased in 1917, during the formation of the United Steel Companies, he was appointed a local Director. In 1920, he succeeded Mr. Mannaberg as Managing Director and in 1923 was appointed a Director of The United Steel Companies. In 1932, Mr. Henderson was appointed Deputy-Chairman of the Appleby-Frodingham Company, a position in which he continued to serve after his retirement from active management of the latter Company in 1934.

Mr. Henderson had been connected with the steel industry for nearly 60 years, during which time he was closely associated with many significant developments. In 1906, for instance, the Frodingham works adopted the Talbot process. At the end of the last century, experiments begun at Frodingham culminated in the adoption of blast-furnace gas engines for the generation of power and for blowing the furnaces. The Appleby plate mills, which are claimed to represent the best plate rolling practice in Europe, were completed in 1927, in Mr. Henderson's term as Managing Director. A further important step in the reorganisation of the plant was taken ten years later with the construction of two of the largest blast-furnaces in Europe and installation of the most up-to-date ore grading plant.

When the National Federation of Iron and Steel Manufacturers came into being in 1918, Mr. Henderson was a member of the Executive Committee and in 1930 he was appointed a Vice-President. In 1934-1935 he was the last President of the Federation in its old form, during which time he took a leading part in the negotiations and subsequent adoption of the constitution of the re-formed British Iron and Steel Federation and in the appointment of an independent Chairman (Sir Andrew Duncan). That somewhat critical term of office included the first Joint Conference on the proposal that Great Britain should join the E.I.A. held in London in December, 1934, which was presided over by Mr. Henderson. For several years Mr. Henderson was also Chairman of the Iron and Steel Industrial Research Council; he was also a member of the Advisory Committee of the Scientific and Industrial Research Board.

Mr. Henderson had been associated with the Iron and Steel Institute for more than 50 years ; joining in 1892, he served as a member of the Council since 1925 and as Hon. Treasurer from 1934 until 1942. In 1939 he was awarded the Bessemer Medal, the highest award the Institute can confer, and occupied the highest office, that of President of the Institute, from 1942 to 1944. Few men have been better fitted by experience, and by character and temperament, for the duties which fell to him as President of the Iron and Steel Institute during these critical years. During his service as Hon. Treasurer, he took a leading part in the acquisition of the present offices of the Institute. He was nominated an Honorary Member in 1944 and a few months ago his portrait by Oswald Birley was presented to the Institute by the Board of United Steel Companies Ltd. in recognition of his life-long services to the Institute and Industry.

Among the many other official positions he held, include that of Chairman of the Lincolnshire Iron and Steel Institute from 1919 to 1921 ; and of the Lincolnshire Ironmasters Association from 1928 to 1935 ; President of British Steelwork Association during 1937-1938 ; while in 1937 he was nominated an Hon. Member of the Verein deutscher Eisenhuttenleute. In civic life he was a Justice of the Peace and for many years was a member of the Lindsey County Council.

Mr. James Henderson had filled with conspicuous success almost every position of responsibility in the steel industry and with all his success he remained a modest and approachable man, always willing to assist, in every possible way, the improvement of the steel industry. He has set up a tradition of service to this industry which may be equalled in the days to come, but is unlikely to be surpassed.

The Iron and Steel Industry
Autumn Meeting held in London

The British iron and steel industry is suffering from the aftermath of war and is likely to continue to suffer for some time, under the circumstances, however, this meeting was very creditable and encouraging and indicates the interest being taken in research matters generally. Reference is made here to some of the papers presented at the technical sessions and to the discussions which followed.

THE Autumn Meeting of the above Institute was held at the offices of The Chartered Surveyors' Institution, Great George Street, London, S.W.1, on November 22 and 23, 1945, the President, Mr. Arthur Dorman, being in the Chair. The meeting comprised three sessions at the first of which, after passing the Minutes of the previous meeting, the President reported the death of Sir Alan Macdiarmid, who was a President of the Iron and Steel Federation, and of Mr. James Henderson, who died two days previous to this meeting and who was a former President of The Iron and Steel Institute. In his reference to these losses to the iron and steel industry, the President said " Sir Alan Macdairmid always inspired quiet confidence. He was a great friend of many of us and a leader in the industry. His brain and initiative brought into being the big new works at Corby and he did yoeman work as President of the Iron and Steel Federation at one of the most difficult periods in the history of the steel industry. We all knew Mr. James Henderson, a successful President of this Institute, who had been all his life in the steel trade and who was one of the founders of the great Appleby-Frodingham works. We shall miss him very much."

Changes in the Council

President-Elect for 1946 .. Dr. C. H. DESCH, F.R.S.
Vice-President .. .. .. Mr. R. MATHER.
Members of Council .. Mr. R. A. HACKING.
Hon. Members of Council Dr. C. F. GOODEVE, F.R.S. ; Dr. J. H. DONALDSON ; and Mr. J. H. PATCHETT.

The following Vice-Presidents and Members of Council will retire in rotation at the next Annual General Meeting and will be eligible for re-election :—
Vice-Presidents .. Mr. J. R. MENZIES-WILSON ; Mr. C. E. LLOYD ; and Sir WILLIAM LARKE, K.B.E.
Members of Council Dr. J. H. ANDREW ; Mr. W, B. BAXTER ; Mr. GERALD STEEL ; Mr. W. J. DAWSON ; and I, F. L. ELLIOT.

The next Annual General Meeting will be held on May 1 and 2, 1946.

Opening Remarks by the President

In extending a welcome to the many visitors present at the meeting from overseas, the President said that, after so many years' absence, it was encouraging to us to feel they still take an interest in the Institute and hoped that the happy relations, which have always existed with our friends in the same industry overseas, will be maintained and extended.

The President expressed his pleasure that Dr. Goodeve, the new Director of the British Iron and Steel Research Association, had been elected an Honorary Member of Council ; he felt sure that it augured well for the relations between that body and the Institute in the future. An approach has been made to American friends on the prospects of visiting this country in 1947, but it is impossible yet to make any final plans.

Affiliation with local associations was reported. Arrangements have been made with the Lincolnshire Association, the Sheffield Society of Engineers and Metallurgists, the Staffordshire Iron and Steel Institute, the Swansea and District Metallurgical Society, and, more recently, the Cleveland Institution of Engineers. The object of these arrangements is to secure facilities for members of this Institute to meet and discuss subjects of technical interest in the districts. The President emphasised that, in making these arrangements, there is no intention to interfere with the independence of any of the affiliated local societies.

Reference was made to the formation of the Institution of Metallurgists and to the steps which have been taken in conjunction with this new Institution, the Institute of Metals and the Institution of Mining and Metallurgy, to form a Joint Committee on Metallurgical Education. Progress has been made in connection with National Certificates in Metallurgy, but this Joint Committee is regarded as a very important function of the Institute.

Relatively few grants of Carnegie Scholarships have been granted during the war, consequently substantial sums of money for this purpose have accumulated and the Council is willing to consider applications for grants from research workers of universities and works of technical as well as scientific subjects. Normally a single grant will not exceed £250.

Williams' Prize

Amid applause, the President presented the Williams' Prize to Mr. R. W. Evans for his very excellent paper on " The Heating of Open-Hearth Furnaces with Mixed Coke Oven Gas and Blast Furnace Gas." It is a very good practical paper, said the President, of exactly the type that we want, and we are very grateful to Mr. Evans for presenting it.

TECHNICAL SESSIONS

Seven papers were presented for discussion at the technical sessions ; at the first session Dr. H. L. Saunders presented " Distribution of Materials in the Blast Furnace.—Part I," and a second paper on " Sinter and Sintering." At the second session the papers presented were on " Dolomite Linings for Basic Electric Arc Furnaces " and on " Some Design and Operating Features of a New Blooming Mill." The third and concluding session comprised the discussion of three papers : " A Micro-Spectrographic Method for the

Quantitative Analysis of Steel Segregates "; "Sources of Error in Diamond Pyramid Hardness Measurements on Hardened Steel"; and "The Determination of Nitrogen in Ferro-Alloys and Other Materials by Direct Nesslerisation without Distillation." Only brief reference can be made here to some of the papers and to the subsequent discussions.

Distribution of Materials in the Blast Furnaces
Part I

By H. L. SAUNDERS and R. WILD

THE extent of the chemical changes which occur in the various regions of the blast furnace depends upon the time of contact between the gases and the solids. It will be appreciated that neither the ascending gases nor the descending burden can normally move at a uniform rate at all points between the stockline and hearth, for not only does the diameter of the stack vary from one level to another, but the wide differences in the size of the materials constituting the burden introduce segregation, and therefore packing and voids will be very irregular. The blast will flow most readily through those regions where the materials are largest and the gas resistance is lowest. This unequal movement of gas and solids means that contact times vary from place to place as well as with time at any specified position; hence the extent of oxygen removal also changes in like manner.

Chemical change is also governed by temperature; this in turn depends on the rate of heat transfer between the hot reducing gases produced at the tuyeres and the cold material charged at the top. The contours of the isothermals will be determined not so much by the reactions themselves as by the selective channelling of the blast through the burden; the temperature gradients thus created impose limiting conditions upon the location of the regions for the various chemical reactions taking place. Even when a furnace is working well, reduction efficiency both locally and generally may be easily impaired by any new condition, e.g., slip, upsetting the relationship obtaining between the rate of descent of the ore and its corresponding rise in temperature; for unless the isothermals happen to be horizontal the temperature increment encountered over a given vertical distance will be much greater in some cases than in others. Indeed it must often happen that some portions of the burden ultimately reach a high-temperature zone with insufficient preparation and consequently interfere with the proper functioning of the hearth. Whether we are concerned with the contours of the isothermals, the lines of similar gas composition, the optimum zones of carbon deposition, slag formation, or fusion of metal, it may be stated without doubt that until we have a clearer insight into the mechanism of solid distribution, our knowledge of the conditions appertaining to maximum efficiency in any of the processes taking place within the blast furnace can never be complete.

Distribution is indeed a problem covering a far wider field than blast-furnace technology, and even in iron-making it is not confined to the blast furnace alone. Similar problems arise in: (a) the storage of raw materials; (b) the fuel beds of producer and gas machines; (c) lime burning; and (d) the preparation of sintering beds.

How can such problems be best investigated Field tests at Frodingham disclosed a definite relationship between the shape of the isothermals, the iso-CO_2 lines

and the contour of the stockline. This can only mean that stockline segregation must play a very important part in furnace operation, and this fact was partly confirmed during subsequent tests on another furnace at Skinningrove. It would however, have been quite impracticable to study all the different possibilities connected with distribution from full-scale practice, so attention was directed to the use of models.

In the work, described in this paper, which was carried out at the Imperial College, South Kensington, several models were employed of different scales, varying from $\frac{1}{10}$th to $\frac{1}{18}$th (linear). At a later stage excellent confirmation of the laboratory results was obtained when a pilot blast furnace was erected at the works of the Shelton Iron, Steel and Coal Company and a critical series of experiments was repeated on this new and much larger scale.

After giving particulars of the models used the authors describe experiments with spherical materials and with materials of irregular shape in order to determine factors governing distribution. As a result of this work and considering all the streamlining experiments in general, it would seem that although there is some tendency towards segregation immediately after discharge from the bell, the main factor governing distribution is the particular stockline contour already in existence at the moment of discharge, for on this the behaviour of the particles immediately after impact depends. To study such effects in closer detail further experiments were carried out by discharging the contents of the bell on to a natural stockline resulting from the systematic charge and discharge of the burden.

Experimental work was also carried out with a view to determining the extent of segregation from which the following conclusions were drawn :—

(1) The streaming experiments show that some distributive effect occurs at the bell orifice, but its influence on the stockline is only small.

(2) Streaming experiments with mixed burdens show that segregation caused by size and density differences is less than might be expected from a consideration of the behaviour of streams of uniform particles, especially when the batter angle is large; the primary effects are in fact masked by multiple impacts. Nevertheless these differences may in certain cases (e.g., M contour) have an important effect.

(3) The stockline contour is one of the main factors controlling distribution.

(4) The behaviour of particles immediately after impact determines to a large extent the nature of the segregation. In general, dense and small materials remain substantially where they fall, thus building up the ridges, whereas light and large materials roll down into the troughs.

(5) The effects under (4) are generally more marked with irregular than with spherical materials, because of increased frictional forces.

(6) Stockline contour is controlled by the following factors in decreasing order of importance: (a) batter angle; (b) bell/throat ratio; (c) bell drop; (e) bell angle.

(7) Size ratio is more important than density ratio in the exercise of segregation control.

(8) Stockline height governs distribution in the following ways as the distance of fall of the burden increases :—(a) the M form becomes ⋀⋁ ; (b) the V form becomes V ; and (c) the V form becomes ⋁ — i.e., all become more shallow.
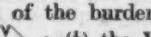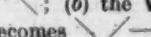
Dr. H. L. Saunders, presenting the paper, said : " It has long been realised that distribution must play a part in blast-furnace operation, but it is only in recent years that the importance of the subject has been appreciated. Very little work had been done on this matter and there had not been any attempt at a systematic study, or even a complete enumeration of all the variables which are responsible for the multitude of patterns which can be worked out. The researches of Kinney, Joseph and Royster in America had indicated the relationship between blast velocity and temperature gradients, and they also made tests on the effect of particle size variation ; but I think it can fairly be said that at any rate as far as this country is concerned it was the work carried out in field tests at Appleby-Frodingham by Dr. Stacey Ward which was responsible for showing experimentally that both temperature gradients and CO_2 concentrations in the working blast-furnace differed from point to point and the question of segregation was put forward at that time as a possible explanation of these phenomena.

" The present investigation on distribution as a separate subject was commenced in 1939 and is actually still in progress. It would be impossible in the short time at my disposal to give even a short survey of all the matters which are concerned in this subject and the present paper, which is Part I of a series, should be regarded as a precis, more or less an A.B.C., of distribution."

The paper was illustrated by a film in two reels, the first dealing with the distribution of solids and blast in the small-scale model used in the laboratory, and relating mainly to normal happenings in the furnace, and the second dealing with the dangers and evils associated with bad distribution or too many fines in the burden. Dealing with the latter, Dr. Saunders said : " Most blast-furnace managers will, I think, admit that these illustrations will strike a familiar note in their memories of incidents encountered in days gone by, which they hope will not occur again, at any rate frequently. Many such difficulties could be eliminated by the employment of control, if such control were applied at the right point and at the right time.

" Some works may not feel disposed to introduce big changes at a time when their major consideration is output, but when fuel economy is the governing factor some change will have to be made. It may be along the lines of closer grading, elimination of moisture, a change in the bell cycle or modification in the bell, but there should be sufficient information available as this work proceeds to enable anyone to ascertain the type of distribution to be expected under given conditions and the manner in which that will change with any changes of the variables.

" It only remains to put the information to the test and we are hoping to do that in our experimental blast-furnace at Stoke-on-Trent. Having done that, the obvious stage to follow is that of putting these results to the test in full-scale practice."

Discussion

Mr. C. A. J. Behrendt : " I am filled with admiration for the ingenuity and the thoroughness of the way in which the authors have tackled this problem, but I must confess that I am a little hazy in my mind as to the practical application of their work, and I hope that they will be able by the breeze of common sense to blow away the fog of doubt which exists in my mind. All blast-furnace men fully realise the importance of the distribution of materials on to and therefore, into the furnace stock column, but I am not sure what I would lay down as correct distribution. The filling on to the stock line and the stock-line contour obtained seem to me to be reasonably easy of attainment by means of bell size and angle, throat design, but I am not convinced about what occurs when some of our materials start their progress down the stack. As the materials are put in at the top, there is a persistency right down to the bosh. This I accept and admit, but the mechanics of it are a little obscure to me ; and the authors' flow lines, which have necessarily been done on materials which suffer no change on their downward passage, do not seem to me quite to fill the bill.

" What of the ores that we use in our North Lincolnshire practice ? We can charge our ore, or at least some of it, in nice pieces, as shapely as cricket balls, but after a comparatively few feet of travel downwards each cricket ball becomes half-a-dozen badly used golf balls and before it gets midway down the stack it is probably more like half a bucketful of hen food. Surely that must have altered the distribution enormously.

" The coke is, in my view, the only component of our stock column that remains reasonably stable from a physical point of view and even that by fracture and abrasion must alter fairly seriously. Even if we indulged in what has been something of an ideal with me for a long time, and charged our materials in a greater range of separated size fractions, I am afraid we should still find that the authors' nice, orderly flow lines became thoroughly disturbed and distorted at an early stage. Moreover, I cannot refrain from mentioning that although we charge our ores and for that matter our coke too, in a mixture of sizes, from, say 4 in. down to $\frac{1}{4}$ in., however much we have played with other charging sequences, we inevitably revert to intimate mixing of coke and ores. We have tried layer charging, thick layers, thin layers, stratification and so on, but we always come back in the end to an intimate mixed charge. It seems to me that it is logical to assume that the smaller the particle the more rapidly it is affected by heat and gas action, with the result that there is apt to be a very heterogeneous mass in various levels and in various annuli in the stock column, which would upset any theory of orderly flow.

" It does really seem to me that having succeeded in obtaining the stock line contour which we require, or think we require, then beyond slight modifications of manipulation to effect temporary changes which we may find desirable from time to time, the rest of the descent of the stock is outside our control.

" The question I want to put to the authors is this : ' Do they think that experiments with the materials which they have used, which are subject to no change on their downward path, can give at any time a representation of the movement of materials which are constantly altering physically in the furnace ? Is not the contour of the stock line the one and only thing over which we have a reasonable chance of establishing control ? ' "

Sir Alfred Egerton, F.R.S.—The only way in which science can contribute to progress is by a process of breaking up the problem into its primary factors, each of which it can deal with alone, and then seeing how to put the picture together afterwards. I feel that the work which the authors have done has been in accordance with the true principles of the methods of science

and will therefore help in dealing with any problems of distribution in the blast furnace.

Mr. Behrendt thought that this work might be too far removed from practice, but when we know what the different sizes of particle do in different parts of the furnace, it is possible to put the picture together afterwards. Of course, the question of what happens at high temperatures is another matter, although a good deal of deduction is possible from the experiments carried out at low temperatures as to what will be the behaviour at high temperatures. We hope, however, to be able to test what is happening when the changes are occurring in a furnace by means of the experimental blast-furnace which is being put up at the present time.

Dr. L. Reeve.—There was one point which struck me rather forcibly. In a way, it is the same point that Mr. Behrendt has made, and concerns a confusion of thought on the subject of persistence of stock running and persistence of distribution. I think that we have to take persistence as absolutely proved by the work on gas analysis and temperature distribution of the Americans and also of Dr. Stacey Ward at Appleby-Frodingham. But, apart from Mr. Behrendt's point, the film showed a curious thing on which Dr. Saunders did not comment ; when he was blowing the blast, the persistence of his stock line, except when his distribution was perfect, was a matter of seconds, it broke up completely, and left and right and centre were all mixed up. I should like the authors to tell us whether the conditions of blowing, when the blast was going at what appeared to be a very great rate, were in line with the size of the model.

Mr. R. P. Towndrow.—We must congratulate Dr. Saunders and his colleagues heartily on giving us a very powerful weapon of diagnosis to give us a lead on some of the problems which beset us in day-to-day furnace operation. It is immaterial whether this method gives us an exact picture. Indeed, the authors will not claim that it does—in some of the pictures the conditions were, I imagine, deliberately exaggerated in order to bring out certain points. But the picture does show us the tendencies which we may expect, and that is what the practical man wants to know, and I think that both the paper giving different sets of conditions and the film have provided us with a most powerful tool, if only as a stimulus to our imagination to help us realise what can happen in the furnace.

Mr. R. Sharp.—These experiments prove that the bell and hopper creates segregation in the furnace, and what I should like to see is some other form of charging the furnace which does not create segregation.

I remember when I was quite a youth seeing sketches of different forms of bell construction which did not consist of just a bell and hopper but of annular rings so arranged as to give in the furnace four lines of segregation. I have also felt that some other device could be developed which would give an even distribution over the furnace top. From the point of view of the blast furnace manager and the blast furnace engineer there is no chance of experiments of this sort ever being put into operation in practice, but if on an experimental furnace of reasonable size something of that kind could be proved to be helpful, it would be an asset.

Authors' Reply

Dr. H. L. Saunders.—There are, of course, limitations in this experimental work. Mr. Behrendt has referred to this, and so has Dr. Reeve. Mr. Behrendt referred to

changes in the materials as they go down the furnace. It is obvious that there are changes—the size changes, the nature of the materials changes, there is slag formation, sintering and so on. All that I can do about that is to ask Mr. Behrendt to be patient a little longer, because we have some rather interesting experiments in progress on gas producers, dealing with the wastage of fuel and ashes, and I think it may be possible to extend those and tie up with something in that connection.

Mr. Behrendt also asks what is the ideal distribution in the furnace. I think that that is for the blast-furnace manager to say—he knows, and we will tell him how to get it. Everybody will have his own ideas, but if we are told what they are we will tell you the easiest way to attain what you want. With regard to Dr. Reeve's question, the cases to which he refers were extremes.

Reference has been made to special methods of charging. There is no reason why you should not have a different method from the old bell and hopper.

I want to make a statement with regard to the experimental blast furnace. I want someone to run that furnace from the practical standpoint and I think that members attending this meeting are more likely to know individuals of the right type than I am. If anyone is interested, or knows of anyone who may be interested, in working in conjunction with this research team on blast-furnace technology, I would ask him to communicate either with the Research Association or myself at the earliest opportunity.

Sinters and Sintering.—Part I
By H. L. Saunders, Ph.D. and H. J. Tress, Ph.D

THE blast furnace is a long-suffering machine that year in and year out is expected to achieve a reasonable output of iron on the crudest of diets ; the marvel is that any survive a lifetime of a million tons output. The use of sinter in the burden is a development of comparatively recent date and has been acclaimed with varying degrees of enthusiasm as an antidote to many ills. Yet, beyond the fact that sintering affords a valuable means for the utilisation of fines, opinions regarding both the essential qualities of a good sinter and the chemical changes involved during its manufacture are as diverse as the constituents from which the sinter is made. So often is this state of affairs the consequence of an inadequate scientific background. We first encountered sintering when studying high-temperature equilibria, and had to take special precautions to eliminate it. More recently the subject has re-appeared in connection with reducibility tests ; we have since examined the problem from many other angles and it is now possible to make a general survey of the physical and chemical changes involved, together with a more detailed study of special aspects of the process which seem to have an important bearing on the future development of blast-furnace technique. Large numbers of laboratory-made sinters, in addition to a dozen or more commercial samples, have been examined. By preparing the laboratory specimens under carefully controlled conditions, it has been possible to correlate various factors which are described in this paper. Although the data may still be incomplete, the authors felt that a critical survey in the light of present knowledge may help to clear the way for a better understanding of, and possible improvements in, sinter production.

This general survey gives some indication of the

many problems associated with sintering, from which it is apparent that the commercial product can be improved if some form of temperature control is introduced. Various suggestions have been put forward and there may be others. Whilst the kiln method may prove to be the ideal, there is considerable scope for modification along the lines indicated and some combination of these may afford a useful compromise, especially when war-time controls are relaxed sufficiently to permit individual blending tastes to be satisfied. Meanwhile it will be well to remember that it is a mistake to use any and every kind of iron-bearing material that happens to be at hand for the making of sinter, in the hope of securing its ultimate reappearance as metal, without due consideration of all the factors involved. Closer scientific co-ordination is imperative between the selection of the raw materials, the computation of the mixture, the grading of all constituents, the assessment of moisture, the control of segregation, and finally time /temperature regulation to secure a sinter suitably balanced as regards mechanical strength and high reactivity, best suited to the particular requirements of the furnace in which it is being employed.

Discussion

Dr. L. Reeve.—This paper is really a combination of two papers. One deals with certain laboratory experiments on sinter, and the other, which is more or less intermingled with it, is an attempt to apply some of the results and make practical suggestions to the sinter plant operator. Taking the laboratory side first, I think that the method of working is rather interesting. It ties up with some work which we ourselves have been doing. There are, however, one or two points of comment and possibly of criticism, which the authors may be able to clarify. I refer to a particular mixture—I gather a self-fluxing mixture—in which a difference of temperature of $\pm 10°$ C. is shown to produce remarkable differences in the constitution of the sinter. I should like to ask the authors whether the conditions described must be regarded as artificial or whether it is suggested they occur in practice. I gather that Dr. Saunders suggests they occur in practice, and indeed that may be the explanation of some of our troubles. If the variability is so high, we are in for a difficult time. I think that the conditions must be slightly artificial, because later on, the authors show that over a fairly wide range of temperature, well over 100° C., fairly good sinters are being made.

On the more practical side—it might be better to call it the control side—I am glad that Dr. Saunders, in introducing the paper, has emphasised the point that too much has been said about the reducibility of sinter and not enough about its strength. From the point of view of the practical man, strength is the variable which is far more important than reducibility. The blast-furnace man's complaint is not that his sinter is or is not reducible, but that it is variable—friable one day and strong the next.

Dolomite Linings for Basic Electric Arc Furnaces

By E. C. Brampton, H. Parnham and J. White, Ph.D., D.Sc.

THE severity of the conditions to which refractory linings are subjected in the basic electric furnace is indicated by the fact that the life obtained is generally only one-third to one-quarter of that obtained in com-parable positions in the open-hearth furnace. The special conditions to which the refractory is subjected in the arc furnace are discussed, and the need for collaboration between the refractory maker and the furnace user is stressed.

In this paper brief account is given of the development of basic linings for electric furnaces, with particular reference to the development of the 100% dolomite brick, which has been widely adopted in this country in recent years. The advantages of this brick are discussed. An account is given of a trial in a 4-ton furnace of a 100% dolomite brick roof which gave a life of 57 heats under severe conditions. Clear indications were obtained during the trial that such a roof would make the attainment of higher furnace temperatures possible and would materially increase side-wall life.

A review of refractory performance data supplied by the users of furnaces in which 100% dolomite brick linings are employed is given, and the general method of installing such linings is indicated and illustrated by diagrams. The methods of manufacturing dolomite bricks, both of the stabilised and of the 100% type are described in general terms.

An account is given of a series of investigations relating to the behaviour of 100% dolomite bricks in arc furnaces. A notable feature is that, as a result of drainage and of migration of lime in the form of fusible compounds away from the hot face, the working face of the brick tends to acquire increased resistance to fluxing while in service. X-ray analysis shows that in used bricks the zone in the immediate vicinity of the working face consists mainly of spinel and periclase, with other divalent oxides in solid solution. Analytical and X-ray data are also given for the principal zones formed behind the hot face in portions of brick removed from a furnace at the end of the oxidising and reducing periods respectively, and the effects of the fluctuating atmospheric conditions are discussed. It is shown that the phases identified in the various zones are consistent with known equilibrium phase data for the system $CaO–MgO–Fe_2O_3(FeO)–Al_2O_3–SiO_2$. The occurrence of " flaking " or splitting-off of the brick at a position between 1 and 2 in. behind the hot face, which sometimes occurs with dolomite bricks (as well as with other basic refractories) as a consequence of flux penetration, is also described and possible mechanisms discussed. Stress is laid on the importance of maintaining adequate support at the hot face and of avoiding excessive undercutting to ensure optimum performance.

The application of the method of sulphur printing on bromide paper to demonstrate the presence of sulphur as sulphide in used bricks is also described, and it is shown that the concentration of such sulphide is low in the vicinity of the hot face and reaches a maximum in certain light-coloured zones some distance into the brick. This is probably responsible for a certain " softening " observed in used bricks in a zone immediately beyond the limit of flux penetration.

Analyses are given of gas samples drawn from furnaces during the refining (reducing) period. These indicate that very highly reducing atmospheres may arise at certain stages of the refining process and that reduction of iron oxide at 1600° C. to a stage intermediate between FeO and Fe_3O_4, but approaching the former, is to be expected.

Samples of refining-period fume have also been analysed, and the " fixed " constituents were found to

be mainly MgO, CaO, iron oxide, and silica. There was also an appreciable content of carbon, apparently combined, and of sulphur as sulphide. The mechanism of fume formation is discussed, and its importance as a source of flux deposition on the refractories is indicated. Its composition is such that basic refractories will be much less affected by it than acid refractories.

Discussion

Dr. J. H. Whiteley.—This paper records progress in the manufacture of dolomite bricks. I found it very readable and interesting. Towards the end it became a little "sticky," but I think that that is excusable, because it is probably true to say that the more our knowledge advances the more our ignorance increases. I take it from reading this paper that the main object in making and proving these bricks is in the first place to increase their durability—and with that, being a steelmaker, I have no quarrel—and secondly, to be able to make steel at a higher temperature in the furnace. As regards open-hearth practice, I doubt very much whether that is really advisable ; my belief is that if you want to make a really first-class steel in the open-hearth furnace—I shall leave the electric furnace alone for the present—there is an optimum temperature at which you must work, and that temperature, it so happens, is just below the point at which the refractories begin to give trouble by melting and getting sticky.

The authors show that sulphur penetrates into the bricks, and it is interesting to note that they get the same amount of penetration of sulphur as was found some time ago in monolithic linings and recorded in a paper for private circulation. The sulphur content in those linings went up to 1% at the bottom of the hearth and the authors have much the same percentage in these bricks. I want to suggest that that penetration of sulphur is due to the formation of iron sulphide, and not calcium sulphide Iron sulphide and iron oxide form a very fusible eutectic. It melts about 900° C., it is very liquid and has great penetrating power.

Continuing, Dr. Whiteley referred to the analysis of the gases in the furnace. It is a most remarkable thing, he said, that if the authors had taken a fourth sample—they have taken three—one has the impression they would have found no nitrogen at all. They say that this low nitrogen—12·0 % in one case—is due either to absorption or to stratification. I suggest to the authors that they should test for stratification by taking four samples simultaneously, and see whether the nitrogen varies from the top to the bottom of the furnace. It is a very interesting point, and I do not think that it should be left where it is.

Mr. F. T. Bagnall.—This paper is very interesting from the point of view of electric arc furnace practice. My remarks are made from the view-point of an electric steel maker, and not from an academic point of view. We do appreciate that the type of lining we use to-day, the chrome-magnesite brick and the dolomite brick, has made it possible to secure a reasonable furnace life with high voltages. The removable roof should, in theory, have a bad effect on refractories in general ; but the figures given in this paper for different furnaces, some machine charged, some hand-charged and some basket-charged, show that the open roof furnace gives as good a life of side-wall as the fixed roof, indeed the figures generally indicate that the open roof type give a better life of side-wall on the facts as given.

Many prefer to ram with dolomite to the top rather than to use dolomite bricks, but the dolomite brick is better, because it is much easier and quicker to brick a wall than to ram it, and if, having rammed a bottom, it is possible to slip a few bricks in crowns and squares in that form it is easier, cleaner and better from the point of view of output than ramming to the top.

Mr. A. G. E. Robiette.—Mr. Bagnall raises the point that if you have an open-top or swinging-roof furnace you get on the whole a longer life. That is quite understandable, even in spite of long arcs, because an open-top furnace can be filled flush to the roof ; the arc is thus buried and the side-wall is shielded during the whole time of breaking down.

The authors refer to some furnaces with Crespi bottoms, but they have not compared Crespi side-walls with their dolomite bricks, and I should like to know whether they have any figures bearing on that, because I have seen furnaces which have given 350 heats with Crespi side-walls—small furnaces used in foundry practice, where normally hotter steel is needed than for making ingots.

Mr. W. L. Kerlie.—This paper is an excellent contribution to the work on electric furnace refractories generally, apart from its reference to dolomite. It would appear that the performance of the S.S.D. brick is equally as good as the performance of rammed dolomite and from a production standpoint there is no doubt that the facility with which the S.S.D. brick can be installed is a tremendous asset. In general, the mode of failure is somewhat similar to that of rammed dolomite linings, and this is not surprising in view of the fact that the materials used are essentially the same.

One can imagine in an electric furnace that the hot face has reached a temperature above 1300° C. and extends to a depth in the region of 2 in., so that the front face will be in a shrunken condition, whereas below 2 in. deep the dolomite will be in its most expanded state. It seems more than likely, therefore, that that front face will shear off, not only due to the effect of the fluxes but also because of that shrinking which takes place. Whether this is the case or not in actual practice still remains to be seen, but it would be interesting to have the authors' opinion on that point.

Can any indication be given whether the rate of heating of the furnace in the first instance is likely to have effect on the flaking since with a fast rate of heating the front or hot face of the dolomite brick may frit very thoroughly and prevent penetration of fluxes ?

Authors' Reply

Dr. J. White.—Dr. Whiteley referred to the paper as being a little "sticky" at the finish. We do not regard the experimental work described in the paper as being complete. Certain avenues have been opened up which we should like to follow, but we do not contend that the last word has been said.

On the question of optimum temperature, we make the point in connection with the basic roof that one of the advantages is that it is possible to get a higher temperature. I am not competent to discuss the question of the optimum temperature of steel-making, which Dr. Whiteley has raised, and I can only say that the users of this particular furnace expressed the opinion that it would be of advantage if a higher temperature could be obtained. It is generally stated that higher temperatures would speed up production by the open-hearth process. That is a matter which can be settled in time, when the steel-making data become available.

With regard to sulphur penetration and the question of iron sulphide, we do not make any definite claim to having identified calcium sulphide, but we favoured the idea because of the white colour, taking the view that it might be calcium sulphide or possibly calcium sulphate.

Coming to Mr. Bagnall's remarks and dealing with the question of the open roof, in the introductory part of the paper we summed up the probable factors involved and the opinions expressed to us by certain operators, and so on. Considering Mr. Bagnall's remarks divorced from the consideration put forward by Mr. Robiette, it would seem that a removable top is a factor which would help ; but I am inclined to think that Mr. Robiette has provided the probable explanation. There are probably two factors involved, one acting against the other. In any case we do not want to be dogmatic on that point at all.

In connection with the length of life, our figures will necessarily be limited to a certain extent by what are the views of the operator on when the wall should come out. We are familiar, of course, with the consideration which makes the user put his furnace off at the end of the week. That does complicate the issue when considering figures of that kind. I was interested to hear that the larger furnaces were giving 160 heats. It is suggested in the paper that a larger furnace, with the walls further from the arcs, has a better chance of giving longer wall life ; at least, we think so and in connection with some of the rather phenomenal figures claimed for American furnaces, we think that that is probably a factor.

With regard to Mr. Kerlie's remarks, we think that in the choice between bricks and a rammed lining the ease and speed with which a new lining can be installed is an important factor. There seems little doubt that bricks are much easier and quicker to install and most users seem to be influenced sooner or later by this fact. Very often we find them swinging over from the rammed type to brick for that reason ; that is their main consideration, apart altogether from performance figures, so long as the performance is comparable, as I think that probably it is. I am not going to make claims for one against the other. The figures that we have, indicate a comparable life, rather than one material is overwhelmingly better than the other.

Some Design and Operating Features of a New Blooming Mill

By G. A. V. RUSSELL and G. W. FOX

THE paper discusses the design and operating features of a new 43-in. reversing blooming-mill installation which has replaced a lighter mill at the Templeborough plant of The United Steel Companies, Ltd. Allusion is first made to the general layout of the plant and then the mechanical design of the new mill is considered, the mill train, main tables and manipulator being dealt with in turn. The roll design and rolling practice adopted are next described and some results of actual performance are included. The paper concludes with reference to certain improved auxiliaries which have been installed, such as a four-way hot-bloom deseamer and a new type of preheating pit furnace for ingots. During ten weeks towards the end of 1944 this mill had an average net weekly of 12,701 tons.

Mr. G. W. Fox, in presenting the paper, said with regard to the performance of the mill, more recent figures are available. From September 1 to November 1945, the total is 133,849 tons, or a weekly average of 13,384 net ingot tons, as compared with the weekly average of 12,701 tons given in the paper. This increase of 683 tons has been achieved in spite of the reduced average ingot weight of about 10 to 12 cwt., due to a large proportion of bought ingots ; in other words, our steel shops are not producing as many ingots as the mill can deal with.

Discussion

Dr. C. H. Desch.—We are greatly indebted to the authors of this paper for giving us such a full account of a mill the design and operation of which have obviously been very carefully thought out, so that the information given in the paper should be of very great value to those who are concerned afterwards with the erection of new mills. Now that the Rolling Mill Research Committee is very active, the provision of such information as is given here will be of great value, I am sure, to the whole industry.

I wish to refer to only a few small points in the paper. The description of the hardening of those portions of the roll on which the really heavy wear comes interested me greatly. One would like a considerable hardness in the rolls if it were not for the fact that there is then always a danger of brittleness. The means given in the paper, by which the collars are hardened by the deposition of a hard alloy, overcomes that difficulty. The parts on which the really serious wear comes are hardened, and one can use a comparatively soft steel for the roll forging, leading necessarily to a very considerably diminished breakage. That, I think, is an important development and it will be of interest to all those who are concerned with the construction of mills.

I should like to ask one question about the bearings. I notice that white-metal-lined bearings are used. I wonder whether plastic bearings have been considered, and if so, whether the authors could give us their views on the relative value of white-metal and plastic bearings on mills of this type.

Mr. G. W. Fox (in reply).—With regard to the hard facing of the collar sides, to which Dr. Desch referred, that actually came about at the building of the mill, when I happened to find a pair of rolls, with a bad flaw, which we had forged and intended for Appleby-Frodingham. On looking at them and measuring them up, I found that we could bring them in for the Templeborough plant, cutting them down, which would get rid of the flaw, but I found they were only 0·33% carbon and the side wear develops very quickly, particularly with a low carbon like that. I had toyed with the idea of welding rolls after what I had seen in the United States with stellite, and we did that with this particular pair of rolls. They gave us our best life, namely 320,000 tons and when they had done the 320,000 tons the pass widths were more or less the same as when we started, so that we got not only a longer life but a more constant bloom, which is a matter one must be very careful about, particularly when feeding a continuous mill.

We have been looking into the question of plastic bearings ever since 1937, but our water supply is not of the best, and we therefore made up our minds to go over to the white-metal bearings, with a very thin lining of only ⅞ in.

IN these columns we have, from time to time, discussed the true fount of microchemistry in this country—microchemical instruction. Such discussion can now rest on a sounder basis. A recently published report, " The Teaching of Analytical Chemistry in Great Britain, with Special Reference to Microchemistry," was sponsored by the Microchemistry Group, and is derived from information collected from the more important teaching institutions of the country, both University and Technical. Not only is it important to know, as this report shows us, that a high percentage of these Institutions have some provision for teaching microchemistry, and that the majority of them continued to teach the subject even under war-time conditions of short staff and short space. But it is even more interesting to learn that out of the Institutions, sixty-four in number, which replied to the questionnaire submitted to them, over fifty per cent. believe in the necessity for teaching the subject, to a greater or less degree, to undergraduate students. This means that at least fifty per cent. of the trained chemists turned out in this country will be aware of the advantages to be derived from the techniques, and will have some acquaintance with their application. The number may, indeed, be considerably greater than this, as in most cases the larger centres of instruction might be assumed to be well to the fore. This is a highly satisfactory condition, following immediately on five-and-a-half years of world war. In ten years time, the figure should be a hundred per cent.

The Micro-Analytical Chemistry of Antimony

By F. T. Beaumont

Methods of detection, separation and determination of small amounts of antimony are reviewed

The Detection of Antimony

1. *Deposition of the metal* may be carried out on platinum foil or wire, by the action of nascent hydrogen on soluble or insoluble antimony compounds. Hydrogen is usually generated by the action of zinc on hydrochloric acid. The antimony is deposited as a dark, rough stain, and 20 μg. may be recognised in a dilution of 1 : 2500.[1] The deposition may also be made on pure, electrolytic copper, by boiling a small piece of copper foil with a solution containing Sb^{III},[2] in the presence of a reducing agent.

2. *The Luminescence Test* is described by Feigl[3] and depends on the fact that antimony and its compounds impart a green-blue luminescence to a hydrogen flame.

3. *Spot Tests* are well represented among the methods for the detection of antimony. The *phosphomolybdate test* is capable of detecting $0 \cdot 2 \eta g$. in a dilution of 1 : 250,000.[4] *Rhodamine B* will detect $0 \cdot 5 \mu g$. at a dilution 1 : 100,000, in the presence of a large excess of tin ;[5] for this reaction the antimony must be in the quinquevalent state. The reaction between a mixture of *antipyrine and potassium iodide* and a solution of Sb^{III}

in 1 : 5 hydrochloric acid will detect one part of the element in 200,000 parts of solution.[6] An iodoantimonate is formed as a golden yellow precipitate. Bismuth, under similar conditions, yields a red precipitate, and tin a white one. The reaction may be applied to the solution obtained by digesting the arsenic sub-group of sulphides with hydrochloric acid ;[7] or the sulphides may be evaporated with aqua regia, the residue dissolved in hydrochloric acid and reduced with formaldehyde.[8] The reaction of *stibine with silver nitrate*, which yields a brown stain, may be used for the detection of traces by passing the suspected gas through a tube, the walls of the tube being moistened with silver nitrate solution.[9] A special gas detection apparatus, used originally for the detection of antimony and arsenic in organic compounds,[10] may be employed for this reaction.

The use of *2.3.7.-trihydroxy-9-methyl-6-fluorone* for the detection of antimony, together with the preparation of the reagent, has been described.[11] An alcoholic solution yields bright red colorations or precipitates with Sb^{III} or Sb^V at pH4, and at this pH tin, arsenic and bismuth

1 Feigl, F., " Qualitative Analyse mit Hilfe von Tupfelreaktionen."
2 Evans, B. S., *Analyst*, 1923, **48**, 557.
3 Feigl, F., *loc. cit.*
4 *idem, ibid.* y Arnal, T. G., *Anal. Fis. Quim.*, 1928, **26**, 181.
5 Eegriwe, E., *Z. anal. Chem.*, 1927, **70**, 400 ; Rosenthaler, L., *Mikrochem.*, 1937, **23**, 194 ; Feigl, F., *loc. cit.*

6 Caille and Viel., *Compt. rend.*, 1923, **176**, 1759.
7 Gautier, J. A., *J. Pharm. Chim.*, 1936 (viii), **23**, 283.
8 Gutzeit, G. and Weibel, R., *Arch. Sci. Phys. Nat.*, 1934 (v), **16**, Suppl. 33
9 Weeks, J., *Chem. News*, 1923, **126**, 275.
10 Wilson, C. L., *Analyst*, 1940, **65**, 405.
11 Duckert, R., *Helv. Chim. Acta*, 1937, **10**, 1122.

do not interfere.[12] The limits of identification are from 0·2 to 0·8µg., according with the use of spot plate and filter paper, respectively.[13]

10µg. of antimony in 1 ml. of solution will form a red colour on the addition of 0·5 ml. of 0·1% potassium iodide, 1 ml. of 20% caustic soda and 5 ml. of 0·01% *gold chloride* solution, but many other cations interfere with the reaction.[14]

A method which employs the orange colour of precipitated *antimony trisulphide*, has been described for the toxicological identification of antimony.[15] Organic matter is first destroyed with nitric acid, lead and barium are precipitated as sulphates and are collected with antimonic acid, lead is then dissolved with ammonium acetate. The residue is suspended in ammonia solution, hydrogen sulphide is passed in, barium sulphate is filtered off, and the antimony trisulphide colour is developed on acidifying.

4. *Microscope Tests* for the identification of antimony are also plentiful. The *pyrogallol test*[16] depends upon the formation of an insoluble antimonous pyrogallate, with crystals of a characteristic angular shape, when the solid reagent or an aqueous solution is added to a dilute hydrochloric acid solution of an antimonous salt, preferably in the presence of tartaric acid. Other metals, including bismuth, form precipitates in neutral, but not in acid, solutions. When a drop of a solution containing antimony pentachloride is allowed to mix with a drop of *sodium chloride* solution (17 g./litre), crystals which are said to have the formula $SbCl_5.NaCl$ are formed, and are recognised as four-pointed stars. Stannic salts under similar conditions yield six-pointed stars.[17] When a little solid *caesium chloride* is mixed with a drop of hydrochloric acid solution of an antimonous salt, crystals of a hexagonal shape are deposited;[18] if bismuth is present, it forms rhombs with the reagent. Once the crystals have formed, the sensitivity of the reaction may be increased by the addition of potassium iodide, when coloured iodoantimonate and iodobismuthate of caesium will be formed. A mixture of *tetra-ethylammonium chloride and potassium iodide* reacts with antimonic, antimonous and bismuth salt solutions in hydrochloric acid, forming double iodides of the quaternary cation and the metal.[19] The double salts have characteristic forms. When a solution of an antimonous salt is treated with *iodine in ethyl alcohol* and the whole evaporated, orange crystals of antimony tri-iodide form; if ammonia is added, the orange colour is destroyed and gives place to a white double compound, $SbI_3, 3NH_3$.[20] Antimony is readily distinguished from bismuth in this test, the latter yielding an orange colour after the ammonia treatment. Other microscope tests for antimony include the identification of a basic oxalate $Sb(OH):C_2O_4.H_2O$ and of potassium antimonyl tartrate, $KSbO. C_4H_4O_6. H_2O$[21]

The Separation and Determination of Antimony

In the following paragraphs some methods which are well suited to the separation and determination on the micro and semi-micro scales are presented. *Phenyl-thiohydantoic acid*, $NH_2.C:(N.C_6H_5).S.CH_2.COOH$, may be used for the separation from arsenic, by precipitating the antimony from dilute acetic acid solution.[22] Metals of the copper sub-group are also precipitated under these conditions, and must, therefore, be removed. The antimony precipitate may be dried in vacuo over sulphuric acid, and weighed. *Pyrogallol* will effect the separation of antimony from arsenic, tin and lead, by precipitating from a hydrochloric acid solution containing Rochelle salt in excess. A five-fold excess of pyrogallol is used to ensure complete precipitation of the antimony; the precipitate is allowed to stand for two hours, and is then collected, washed with cold water, dried at 110°, and weighed as $HO. C_6H_3O_2:Sb(OH)$. A distinct precipitate is obtained with less than 0·05 mg. of antimony.[23] Another method of separating arsenic from antimony consists in precipitating the former as *magnesium ammonium arsenate*;[24] the antimony in the filtrate is then determined gravimetrically as the trisulphide. A separation of tin from antimony, which is reputed to be highly successful, consists in precipitating the former with *cupferron* in the presence of tartaric acid;[25] salts of the alkali metals should not be present in quantity. *8-Hydroxyquinoline* will precipitate antimony from chloride solutions, quantitatively, at pH 6, as $Sb(C_9H_6ON)_3$, but if the solution contains tartaric acid the precipitate has a somewhat lighter colour and has the formula $SbO(C_9H_6ON)_3$.[26] Great care should be exercised in recommending separations of cations with this reagent, since the liability to co-precipitation is always considerable. A method of separating zinc from antimony has, however, been described.[27]

A number of *volumetric methods* largely adapted from the macro-methods have been utilised for the titration of antimony. The *bromate titration* method has been applied by a number of investigators, e.g., small quantities of antimony in bronzes are collected by dissolving in nitric acid, with the addition of pure tin, and evaporating; the insoluble residue is treated with concentrated sulphuric acid, reduced and titrated;[28] the bromate titration has also been investigated successfully in the case of white metals,[29] organic compounds;[30] tin-base alloys, where the interference of copper (which may cause re-oxidation of antimony to the antimonic state) is overcome by the employment of special conditions of dissolving and reducing;[31] and to lead and lead alloys,[32] where the arsenic, antimony and tin are twice co-precipitated with manganese dioxide, antimony and arsenic are then separated by conversion to the chlorides, reduction, and distillation of the arsenic, and then they are titrated separately with bromate. Titration with 0·002 N *iodine* is useful for the determination of quantities of the order of 1 mg. of antimony;[33] *permanganate* may be used in the determination of 0·01% of antimony in solder; *potassium iodate* for the determination of micro-amounts, in the presence of hydrochloric acid and chloroform.[34] *Ceric sulphate*

12 Wenger, P., Duckert, R., and Blancpain, C. P., *ibid.*, 1427.
13 Wenger, P., Duckert, R., and Blancpain, C. P., *Mikrochim. Acta*, 1938, 3, 13.
14 Schapiro, M. J., *J. Appl. Chem. Russ.*, 1938, 11, 355.
15 Palmeri, C., *L'Ind. Chimica*, 1932, 7, 567.
16 Feigl, F., *Mikrochem.*, 1923, 1, 74.
17 Ortodoceu, A. P. and Remy, M., *Bull. Soc. Chim.*, 1923, 33, 991.
18 Chamot and Mason, "Handbook of Chemical Microscopy," Vol. II, 2nd Ed.
19 Jones, F. T. and Mason, C. W., *Ind. Eng. Chem. (Anal.)*, 1936, 8, 428.
20 Deniges, G., *Compt. rend.*, 1938, 207, 1358.
21 Chamot and Mason, "Handbook of Chemical Microscopy," Vol. II, 2nd Ed.

22 Lassieur, A., *Compt. rend.*, 9123, 176, 1221.
23 Feigl, F., *Z. anal. Chem.*, 1924, 64, 41.
24 Hecht, F. and von Mack, M., *Mikrochim. Acta.*, 1937, 2, 218.
25 von Mack, M. and Hecht, F., *Mikrochim. Acta.*, 1937, 2, 227.
26 Firtea, T. I., *Z. anal. Chem.*, 1939, 118, 26.
27 Cimerman, C. and Wenger, P., *Mikrochem.*, 1939, 27, 76.
28 Misson, G., *Chim. et Ind.*, 1934, 31, Spec. No. 438.
29 Anderson, C. W., *Ind. Eng. Chem. (Anal.)*, 1934, 6, 456.
30 Schulek, E. and Wolstadt, B., *Z. anal. Chem.*, 1937, 108, 400.
31 Luke, C. L., *Ind. Eng. Chem. (Anal.)*, 1944, 16, 446.
32 idem. *ibid.*, 1943, 15, 626.
33 Brukl, A. *Mikrochem.*, 1923, 1, 54.
34 Barber, C. L., *Ind. Eng. Chem. (Anal.)*, 1934, 6, 443.

(0.01N) may be employed as titrant, either with an indicator or electrometrically.[35]

Several authors have measured the density of the *colour of suspended antimony trisulphide*, and have used this as a means of determining small quantities of antimony. Evans,[36] in determining antimony in lead, after some preliminary treatment, deposits the antimony on clean copper foil; the foil is washed, covered with water, and treated with sodium peroxide. The antimony is thus dissolved out, the solution and washings are treated with zinc sulphide, acidified and reduced, gum arabic is added to prevent settling out, and the colour is compared with standards. A similar method is used by Clarke[37] for the estimation of 0·001 to 0·05% of antimony in tin, and for the determination of antimony in copper and copper alloys.[38] Where much organic matter is present, the antimony may be recovered quantitatively by ashing with magnesium oxide and nitrate, acidifying the ash with hydrochloric acid, removing iron and then precipitating the antimony as trisulphide, and measuring the colour.[39] An alternative method for destroying the organic matter is provided by wet oxidation with a mixture of sulphuric and nitric acids, any chloride being first precipitated with silver nitrate; the antimony trisulphide is then precipitated under carefully controlled conditions of acidity.[40] The method of Grant,[41] which employs the electrolytic reduction of antimony compounds to stibine, followed by deposition as in the Marsh test, also finally estimates the antimony by the trisulphide colour.

Other colorimetric methods for the determination of antimony are described by Makishima,[42] who uses the *phosphomolybdate* reaction in the presence of large amounts of copper, and by Fredrick,[43] who adapts the *rhodamine B* reaction, making use of the solubility of the complex in ethyl alcohol and other organic solvents. The colour reaction of *pyridine and potassium iodide* with antimony is applied to the determination of traces in an electrolytic bath and in zinc, after collection of the antimony with manganese dioxide; the precipitate is dissolved in oxalic acid and hydrochloric acid, antimony is deposited on copper foil in the presence of sodium hypophosphite, and is redissolved in water with the help of sodium peroxide, and the colour is developed in this solution.[44] A simplified apparatus and method for measuring the stain produced by *stibine* has been evolved, and is applied to the detection and determination fo antimony in tartar emetic spray residues.[45]

Spectrographic methods have received a good deal of attention. It is stated, in one case, that preliminary treatment of a solution containing antimony, to remove some interfering substances, will permit the detection of as little as 5×10^{-8} g. of antimony; an intermittent or flame arc may be used with solids or with solutions.[46] In another method, the substance to be tested is diluted with sodium chloride, so that various concentrations of antimony are obtained. In each case 0·5% of molybdenum is used as a reference substance.[47] A similar

treatment is applied in the spectrographic determination of antimony in metallic bismuth.[48] Antimony in metallic copper may be determined by separating the sulphide, dissolving in hydrochloric acid, and impregnating graphite electrodes with the solution[49]; or the impurities from the copper may first be collected with ferric hydroxide[50]; or the copper itself may be employed as the reference substance, Sb 2311·5 A being compared with Cu 2303·13 and 2319·56 A.[51] The last mentioned method is successful over the range 0·0005 to 0·1% of antimony. A method has been worked out for the determination of 1 to 50 parts per million of antimony in nickel and nickel salt solutions,[52] using the nickel as an internal standard. Other spectrographic determinations of antimony have been described, and include the determination in aluminium and its alloys,[53] and in brass.[54]

The *polarographic method* has been applied to the determination of small quantities of antimony in aluminium alloys[55] and in battery acids.[56]

Concluding Remarks

In the above necessarily brief descriptions of qualitative and quantitative methods, there will be found at least one possible approach to most of the problems encountered in the microchemistry of antimony, since the range from a fraction of a microgramme to twenty or thirty milligrammes is covered. It will be noted that the methods of separation have been included with the methods of determination. The treatment of the subject is not claimed to be exhaustive of the recent literature, but it is, at least, representative, and shows the trend of present-day investigations in the microchemistry of antimony.

Each one of the methods requires patience, practice and some skill; as in all micro-analysis, scrupulous cleanliness must be observed. A further lesson to be derived from the present study is the high importance of identical treatment of standard samples and unknowns, where the methods are comparative; nor can too much stress be laid upon the running of blank tests on all occasions. The last remarks require repetition until all recognise that blank tests are an essential part of the work.

Wash Bottles

By W. Thomas.

TWO types of wash-bottle are in general use in micro-qualitative analysis. One type is a small-scale reproduction of the conventional wash-bottle in which the water is expelled by pressure exerted by the mouth; the other type consists of a test-tube drawn out to a fine capillary from which the water is expelled by the warmth of the hand. With the former type it is difficult to control the amount of water ejected, particularly when only small drops are required. The test-tube type is not suitable for delivering larger quantities such as may be required when washing precipitates or

35 Rathsburg, H., *Berichte*, 1928, **61** (B), 1663.
36 Evans, B. S., *Analyst*, 1927, **52**, 565.
37 Clarke, S. G., *Analyst*, 1928, **53**, 373.
38 Clarke, S. G. and Evans, B. S., *Analyst*, 1929, **54**, 23.
39 Bamford, F., *Analyst*, 1934, **59**, 101.
40 Couillard, J., *Bull. Trav. Soc. Pharm.*, 1935, **73**, 248.
41 Grant, J., *Analyst*, 1928, **53**, 626.
42 Makishima, S., *J. Soc. Chem. Ind. Japan*, 1931, **34**, 322.
43 Frederick, W. G., *Ind. Eng. Chem.* (*Anal.*), 1941, **13**, 922.
44 Luria, J. J., Tal, E. M. and Fligelman, L. B., *Zavod. Lab.*, 1939, **8**, 1222.
45 Davidson, J., Pulley, G. N., and Cassil, C. C., *J. Assoc. Offic. Agric. Chem.*, 1938, **21**, 314.
46 Riedl, E., *Z. anorg. Chem.*, 1932, **209**, 337, 356.
47 *ibid.*, de Rubies, S. P. and Bargues, M. A., 1933, **215**, 205.

48 Kunina, S. I., Rivkina, M. A. and Rusanov, A. K., *Bull. Acad. Sci. U.R.S.S., Ser. phys.*, 1941, **5**, 300.
49 Park, B., *Ind. Eng. Chem.* (*Anal.*), 1934, **6**, 189.
50 Breckpot, R., *Ann. Soc. Sci. Bruxelles*, 1935, **55**, B, 173.
51 Lomakin, B. A. and Ostachevskaja, A. L., *Z. anorg. Chem.*, 1936, **228**, 14.
52 van Someren, E. H. S., *J. Soc. Chem. Ind.*, 1936, **55**, 136.
53 British Aluminium Co., "Spectrochemical and Polarographic Analysis of Aluminium and its Alloys," 1943.
54 Leichtle, P. A., *J. Opt. Soc. Amer.*, 1944, **34**, 454.
55 British Aluminium Co., *loc. cit.*
56 Walker, —, *Amer. Chem. Abs.*, 1944, **38**, 2883.

cleaning centrifuge cones. Moreover, the method of filling presents some inconvenience.

The type to be described, illustrated in Fig. 1, has some advantage since small or large amounts can be delivered as desired. The container consists of a 2 × ¾ in. specimen tube fitted with a two-holed rubber bung of suitable size, which carries the pressure and delivery tubes. The delivery tube is made from 5 mm. tubing, bent and drawn out as shown in the diagram. A

Fig. 1 Micro Wash Bottle

hair tip is drawn out at the delivery end. The end of pressure tube to which the rubber teat is attached, is widened after softening in a Bunsen flame, by means of a carbon rod. This ensures a tight fit with the rubber teat since the common type is usually too wide to fit satisfactorily over 5 mm. glass tubing.

When cleaning cones by the siphon method,[1] where copious washings may be necessary, the bottle can be manipulated with one hand leaving the other free to hold the cone. This is simply achieved by operating the teat with the thumb and first finger whilst holding the bottle in the palm of the hand with the remaining fingers.
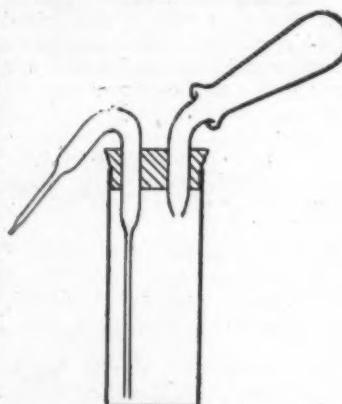
Microgram-Scale Colour Reaction

By J. T. Stock and M. A. Fill

IN order to demonstrate to students some of the possibilities of microchemical technique, the simple device illustrated in Fig. 1 was constructed from scrap glass rod. It allows colour-reactions to be performed with extremely small quantities of solutions, and its use has exerted a corrective effect upon students whose small stock of training appeared to have given them a leaning towards "bucket chemistry."

One end of a piece of 2 mm. glass rod is drawn down into a thread of about 0·2 mm. diameter. The thread is nicked and broken off so that about 5 cm. remains attached to the rod. The extremity of the thread is then fused until a bead A having a diameter of approximately 2 mm. is formed, after which the thread is bent at right angles as shown in Fig. 1. A hook B formed at the handle end of the rod allows the device to be hung on the rim of a beaker when not in use. When a test is to be made, a stand cut from a cork supports the rod horizontally so that the bead is about 5 mm. above the surface of a white tile.

A sample is removed from the test solution by using a glass rod, the end of which is drawn down until almost hair-like. This is immersed to a depth of about 5 mm. into the solution, then withdrawn and the sample applied at point C by slowly drawing the wet tip across the neck beneath the bead. A trace of reagent is then

1 C. C. Miller, METALLURGIA, 1944, Nov., 39.

added in a similar manner. On viewing directly above A and slowly rolling the stem in its cork support, a position is reached at which the bead appears to be illuminated with light of the colour produced in the reaction.

The volumes of test solution and of reagent required are extremely small, and are not easy to determine by direct measurement. Accordingly, a simple indirect method, designed to demonstrate the sensitivity of colorimetric methods, was used. A 5% solution of ferric chloride was prepared, and a normal test portion applied to C by the usual technique. The test portion was then washed off with a few drops of distilled water and diluted to 0·5 ml. after developing the colour with thioglycollic acid in the usual way.[1] Using ignition tubes as micro-Nessler glasses, the amount of iron in the washings was determined by comparison with standards prepared from diluted ferric chloride solution. From the result, the volume of the test portion could be readily calculated. Although the results were naturally not very accurate, they were sufficient to show that the volume of an average test portion was about 0·02 cubic millimetres.

Fig. 1.—Device for examining very small quantities of liquid.

Determination of the lowest concentration of strong acid (or alkali) which can be detected by any of the usual acid-base indicators provides a simple but effective exercise. Starting with N/100 hydrochloric acid solution, aliquots are diluted and tested successively with any of the usual indicators. With these, there is little difficulty in obtaining a positive test with solutions as dilute as N/5000, while the student finds that the iodide-iodate starch indicator is even more sensitive. Taking the average test portion as 0·02 cubic millimetres, he is asked to calculate the smallest amount of hydrochloric acid which he can detect—an extremely small fraction of a microgram. Though the experiment is of no real significance from a microchemical point of view, a little consideration of the results will often do much to induce the state of mind so desirable for the appreciation of the possibilities of microchemistry.

In addition to using the device for teaching purposes, we have found it useful in quantitative micro-analysis, on occasions when it is desired to test the solution with an external indicator.

The report on the Teaching of Microchemistry, mentioned elsewhere in this issue, appeared in the issue of *Nature* for Nov. 17th, vol. 156, p. 588.

In the next issue Dr. Wilson will present a selection of range of methods which have been developed to measure density on a small scale. The microdetermination of density is of interest both to mineralogists in the investigation of gems and rare minerals and to organic chemists as an aid to the identification of compounds.

1 British Drug Houses, Ltd., "Organic Reagents for Analytical Use," 8th Edn., London, 1941, p. 133.

Alloy Steels for Maintenance

By J. A. Rosa.

ALLOY steels are at their best in large sections, such as are commonly encountered in plant maintenance work. The inherently higher tensile strength of alloy steels in large sections is of extreme importance to those who are charged with the responsibility of maintaining plants in full and uninterrupted production. While a plain carbon may be reasonably expected to have an ultimate tensile strength of 45 tons/sq. in. in a heat-treated 1 in. diameter shaft, it would be foolish to use this steel in, for instance, a 5 in. diameter crane hoist shaft which may be occasionally overloaded to 55 tons/sq. in. The inherently higher tensile strength of large section heat-treated alloy steels is due mainly to the higher (or deeper) hardenability of these steels.

The selection and application of any alloy steel for plant maintenance depends on a number of factors. No single mechanical or physical property test can be used to determine accurately all the factors which should be considered in making a selection for a given application. To select a steel properly an analysis must be made of the job. Some of the factors which must be considered in making a selection are : The size of the section ; the strength requirement ; the wear characteristics at high or low hardness ; the notch sensitivity or fatigue endurance necessary ; the response to the desired heat treatment ; the machinability desired ; the method of fabrication ; the resistance to corrosion necessary ; strength-weight ratio ; and present and future availability.

It is noteworthy that the initial cost is not listed as a factor in the selection of steel for plant maintenance work. The reason for this omission is obvious. In these days of safety consciousness, it is sometimes difficult to determine which is the more important : a perfect safety record or a perfect production record. Undeniably, they go hand in

hand. If a plant is so maintained that failures are at a minimum, accidents to personnel will be at a minimum and production at a maximum. To consider only the initial cost of an installation without regard to total maintenance cost is faulty reasoning and false economy.

That alloy steels are at their best in large sections is especially true in parts over 2 in. in cross section. For large diameter shafts on cranes, table-roll trains, conveyers, and other steel mill equipment subject to heavy constant loads or sudden overloads, the deeper hardening alloy steels are particularly favourable. The ability of some steels to harden uniformly to the centre of even the largest sections used in plant maintenance work ensures uniformity of hardness and structure from surface to centre. Because of their shell hardening nature, plain carbon steels cannot give this uniformity of microstructure and hardness in sections over 1 in. in diameter.

In most steel mill applications it is desirable to have a fair degree of ductility in the parts. Failures of parts of high hardness are usually of a brittle nature and generally occur without warning. A ductile part, however, usually gives some warning of impending failure, such as bending, twisting, or stretching. To obtain high strength in carbon steels it is necessary to sacrifice ductility. In doing this the hardness is also increased. On the other hand, an alloy steel will, in most instances, give an equivalent tensile strength at a considerably higher ductility. This means that an application can be made that will possess high tensile strength and good ductility at a relatively low hardness.

The wear characteristics of a steel are of major importance in certain applications. Guides, conveyer parts, drag bars, links, pins and similar parts undergo varying degrees of abrasive wear. In some applications fully hardened, abrasion resistant steel may be used. Other applications call for good ductility at low hardness together

with a high degree of abrasion resistance. No single alloy steel can meet the demands for all applications. The choice of a steel for a particular application may vary from a carburised or nitrided alloy steel of good strength and high ductility to a fully hardened higher alloy type, or even to an austenitic manganese steel of the Hadfield type.

Steel mill equipment has been traditionally built on a massive scale ; probably due to the fact that since early days plain carbon steel has been used in building this equipment. Although no particular advantage is to be gained by reducing the weight of static equipment, direct and indirect benefits result from weight reduction without strength loss in mobile equipment. Cranes, rolling stock, conveyer systems and other forms of mobile equipment designed to the same strength requirement and built with alloy steels will be lighter than their carbon steel equivalents. Decrease in deadweight means lower starting, stopping and operating costs.

The substitution of alloy steels in present carbon steel mobile equipment without change in section or weight will bring indirect benefits in the form of increased pay loads. An example of this exists in one plant where a crane of 110 tons capacity was re-equipped with alloy steel shafting and gears. This crane now has a capacity of 150 tons. This increase in pay load capacity was achieved without adding a single pound to the deadweight of the crane structure.

In the discussion which followed the presentation of this paper the author was asked for suggestions for heat-resisting steels which could be used with advantage around the soaking pits, around the shears or the hot-beds. Some particular items which have given trouble, upon which information was sought, were shear knives, slow cooling pit cradles, bits for stripper tongs or soaking bit tongs.

In reply, the author said that, with regard to shear knives for blooming mills and other hot work shears, his firm is using a 5½% molybdenum hot work die steel. It is used in a heat treated condition and at a hardness

of 387 to 410 Brinnell. This gives a very good life and, in comparison with the steel available before, the improvement in life has been great enough to warrant continuing the use of this die steel. Stripper bits are a problem. We have tried many things, discarded almost everything. Our trouble was not so much with wearing out of the bit itself as it was of breakage of the bit ; it seems to be a mechanical problem rather than one of steel or steel type. We are working on it ; at present

the most logical solution we have is in continuing working with these $5\frac{1}{2}\%$ molybdenum hotwork steels.

For other hot-working applications around soaking pits, annealing furnaces, and so on, the author recommended a steel of the austenitic stainless type, such as 25% chromium, 12% nickel, or even the higher alloying types. They are very good scale-resisting steels and they have high creep strength. They are costly, but, in view of their service life, they do warrant their installation.

A Direct Polargraphic Determination of Lead and Cadmium in Potassium Cyanide Solution

By M. Spalenka

IN polarograp'ic methods for determination of lead, cyanide solutions have hitherto never been recommended as base electrolytes. Since the use of these solutions offers great advantages, procedures were investigated whereby they could be used.

Polarographic procedures are described for :—
1. Determination of 10–30% Pb in lead bronze.
2. Determination of 0·08–4·0% Pb in copper alloys.
3. Determination simultaneously of 0·001–2·0% Pb and 0·001–1·0% Cd in zinc and its alloys and in zinciferous materials.

The analyses are carried out open to the air in the presence of Cu, and Al and of traces of Tl, Sn, Mg and Mn.

1. *Determination of Lead in Lead Bronzes.*

The polarographic method has the advantage of speed over the gravimetric method, but in methods for determination of lead, previously described, the copper wave interferes because of the more positive value of its half-wave potential ; but when using alkaline cyanide solutions, no chemical separation of copper is necessary since its wave is completely eliminated. Thus all operations may be carried out in the measuring flask used for solution of the sample.

The method is as follows :—

A 0·1 gm. sample of the lead bronze is placed in a 100 ml. measuring flask and 5 ml. 4N nitric acid added. The sample is completely dissolved and nitrous fumes removed by vigorous boiling. The solution is now diluted

with about 20 ml. of water and 20 ml. of 2N NaOH solution added. A precipitate of copper hydroxide appears while lead is held in solution as plumbite. Now, 3·5 ml. of alkaline potassium cyanide solution (2N KCN in 1N NaOH solution) are run in. The copper precipitate dissolves and to the clear, colourless, solution an addition of 1 ml. of a 0·5% solution of gelatin in 0·5 N nitric acid is made for suppression of maxima, and 1 ml. saturated sodium sulphite solution to remove dissolved oxygen. The flask is made up to the mark with water and the contents well mixed. About 15 ml. of the solution is polarographed, at a suitable galvanometer sensitivity, open to the air, the curve being taken over the range 0 – 0·6 v. Best results are obtained where a comparison solution is used which contains a known amount of lead. A corresponding amount of copper is also added to give the comparison solution a similar composition to that of the test solution. Then

$$\% \ Pb = \frac{a \times v_x}{v \times m} \times 100$$

l = weight of lead in comparison solution.

v = wave-height of comparison solution.

v_x = wave-height of unknown solution.

m = weight of sample.

When a comparison solution is not prepared, all measurements must be carried out under the same conditions (i.e., capillary, drop time, temperature).

Table 1 gives a comparison of gravimetric and polarographic results.

% Pb (polarographic)	20·0₂	20·0₃	21·0₃	20·5₀	21·4₀
% Pb (gravimetric)	20·0₀	20·1₃	20·9₀	20·6₀	21·4₀
% Pb (polarographic)	..	18·4₃	19·0₃	21·7₅	17·4₀
% Pb (gravimetric) ..	..	18·5₅	19·0₃	21·7₃	17·4₀

If the material is heterogeneous, a greater sample weight may be taken and a 0·1 gm. fraction of its solution analysed.

2. *Determination of lead in copper, brass and copper-containing zinc alloys.*

When the lead content exceeds 0·08%, the polarographic method may be applied to analysis of copper and zinc and their alloys without a chemical separation of copper. A greater weight sample must, however, be taken than of in the case of lead bronze, and also the amount of cyanide increased to obtain a colourless solution and a well-defined curve. Better results are obtained if Hohn's method of " standard addition " is used. The comparison solution method is not recommended in this case, since Al, Mn, Mg and Fe may be present and the results may be influenced by adsorption on the precipitates which they produce. A sample weight of 2·5 gm. is dissolved in 15–20 ml. of 1 : 1 nitric acid in a measuring flask and nitrous fumes expelled by boiling. The solution is cooled and diluted with water to 50 ml. Two 20 ml. aliquots are taken in 100 ml. measuring flasks, to the first of which is added a known amount of lead. Both solutions are diluted to 40 ml. with water and to each flask is added 30 ml. 2N NaOH and the necessary amount of cyanide solution (5N KCN in 0·5N NaOH solution) ; this is 10 ml. for zinc, 13 ml. for brass, 15 ml. for copper. The solutions are well-stirred, 1 ml. of gelatin and 2 ml. of sodium sulphite solution are added and the solution made up to the mark. The two curves are taken and

$$\% \ Pb = \frac{100 h_2 \cdot g}{(h_2 - h_2) m}$$

where h_1 and h_2 are the step-heights

g is the known weight of lead added,

m is the sample weight (1 gm.)

This method has the advantage that the analysis can be carried out without chemical separation. Also removal of oxygen with a gas stream is unnecessary because of the addition of sodium sulphite. Interference by the anodic step of the CN ion is eliminated by avoiding excess of potassium cyanide in the electrolyte.

3. *Simultaneous determination of lead and cadmium in various zinciferous materials. Determination of traces of lead and cadmium in*

pure zinc and in copper-containing zinc alloys.

The half-wave potentials of Cd and Pb are separated by about 200 milli-volts and thus these elements may be determined simultaneously. In previously described methods, tin and thallium interfered and copper had to be removed chemically before estimation of lead and cadmium. The method used was as follows :—

A 7·5 gm. sample of zinc is dissolved in a 50 ml. measuring flask in 10 ml. 1 : 1 hydrochloric acid, 15 ml. of concentrated HC1 and 3–5 ml. nitric acid. After solution, the sample is diluted, cooled and filled to the mark with distilled water. Now, 10 ml. aliquots are pipetted into each of two 50 ml. flasks. A "standard addition" is made to the first flask and both solutions diluted with 5 ml. of water and then with 18 ml. 10N NaOH solution and 7·5 ml. of cyanide solution (5N KCN in 0·5N NaOH solution. A clear solution is obtained on shaking and 3 ml. of sodium sulphite and 0·2 ml. of 0·5% gelatin solution are added. The solution is diluted to about 49 ml. with water and to the mark with 6% SO_2 solution. After shaking and standing for a few minutes, the sample is polarographed, open to the air over $0 - 0·6$ v. range.

When dealing with copper-containing zinc alloys, the amount of cyanide must be increased and the amount of alkali decreased — 10 ml. 11N NaOH and 10 ml. KCN solution is sufficient. The rest of the procedure remains unchanged.

During the analysis of zinc alloys containing copper, it was observed that the oxygen was better removed than in the absence of copper. That is, the step due to oxygen was much lower when copper was present. This is due to the catalytic effect of copper ions on the oxidation of the sulphite. It is therefore an advantage to add to copper free alloys, the equivalent of 4% copper (e.g., 0·06 gm. Cu. on 1·5 gm. sample). The atmospheric oxygen is then almost completely removed and a greater galvanometer sensitivity may be used.

This method may be applied to the determination of $0·001 - 2·0\%$ Pb and $0·001 - 1·0\%$ Cd.

The Electrodeposition of Metal on Plastics

By Harold Narcus

THE electrodeposition of metals on plastic articles has opened up a large new field in electric engineering and electronics, e.g., electric insulation may require screening against magnetic fields, high frequency currents, or radium emanation. Articles made of plastics for these purposes, such as phenols and styrenes, which are excellent electric insulators, are plated with copper, cadmium or lead. Such plated articles combine all of the inherent advantages of the plastic and the required properties of the outer metal surface. The product may substitute one component for two or more others since the plated plastic article will retain its non-conductor properties and at the same time be in part a suitable conductor. This combination of a non-conductor and a conductor promises wide use in radio, television and in electronics in general. An impressive example of such a combination is the manufacture of a specially designed commutator, which demonstrates through selective plating

the ease with which intricate commutating surfaces can be obtained in depressed grooves in a moulded plastic piece.

Metals such as aluminium and magnesium, although now more readily available, are being replaced by plated plastics in aircraft electric shielding and in radio shielding devices. The purpose of this procedure is to eliminate costly inserts and assembly operations to give a product which is lighter, more quickly fabricated, and much more resistant to the vibrations encountered in modern combat aircraft. This vibrational resistance is clearly manifested in the metallised plastic plywood antenna mast which is being used in high speed fighter planes. This mast, which withstands the vibrations of the plane at highest flight speed, is thickly plated with copper or iron. The adhesion of the electrodeposit during flight is surprisingly good.

Another example of the metallisation of plastics is in the manufacture of frequency modulation and television antenna. Their performance is

thereby greatly improved, since the resulting reduction in weight permits a larger diameter tube or rod to be employed in the element, whereby an increase in surface area and consequently in pick-up is attained. The installation of plated antennae is simple.

The deposition of metallic coatings on plastic substances permits use of the so-called "scrap" plastic materials, which ordinarily could not be utilised without further processing. For example, mixed "scrap" plastics of the thermoplastic type, of one chemical structure but of a different colour, can be ground, remoulded and then plated.

The process of plating on plastics is not intended to imitate metal but rather to yield a product that cannot be economically made of metal. More intricate shapes can be readily moulded and electroplated than could be readily fabricated in metal and electroplated. As the weight added by the application of metal to the plastic is usually negligible, the plated plastic part still maintains a weight advantage over a similar part made of metal.

Soldering one metallised plastic component to another or to a metallic unit is now practicable. The process greatly improves hermetic sealing of such electric components as resistors, condensors and small relays, since non-metallic cases can be plated with a properly placed metallic band to be used for subsequent soldering to a metallic end cap, and insulators can be plated and soldered to metallic containers.

Contrary to the beliefs of some, the cost of plating plastics, while somewhat higher than the conventional plating on metal, is low in comparison with the final cost of the plated plastic part and of a similar part made entirely of metal and electroplated with a comparable deposit.

The experiments described by the author show a marked increase in tensile, impact and flexural strength for many synthetic resins plated as compared with the values for the same resins unplated. An appreciable increase in resistance to distortion from heat and a decrease in percentage of water absorption are obtained by complete envelopment of the plastic article in a metallic coating. The most important advantage of plating on plastics is the greater corrosion resistance of a metallic deposit when it is applied to a plastic basis than to the usual metallic basis, since there are no galvanic couples with a basis metal.

The two main purposes for metallising a plastic are : (1) to render it a suitable substitute for critical and strategic metals ; and (2) to produce a product which has the inherent properties of the plastic in addition to the desired properties of the deposited metal.

To render the plastic surface conductive, the methods such as those using fine metal powders in a lacquer or varnish medium, or metal spraying, or cathode sputtering, or metal evaporation, have proven successful but were found inadequate for the majority of production methods in industry. On the other hand, the chemical reduction method described in detail in this paper is best adapted to an economical production set-up. This method involves the application to the plastic surface (after proper preparatory treatment) of a conductive and adherent bond coat by using a solution of ammoniacal silver nitrate or other easily reducible metallic salt and a suitable reducing agent (usually organic), followed by an intermediate layer of electrodeposited copper or silver, and finally by a top layer of the desired metal such as chromium, zinc, iron, lead, nickel, gold, silver or cadmium.

The preparatory treatments of the plastic surface are the governing factors which make for success or failure of a process for plating on plastics, since the chemical structure of the plastic determines the procedure to be employed for the application of the conductive film.

The weight method and the optical method for quantitatively measuring the thickness of the chemically precipitated silver film are presented in detail. The results obtained from each procedure agree amazingly well, considering the small magnitudes which are involved.

change occurs with addition of ferricyanide. With the exception of manganese, the other elements do not react with ferricyanide, but the salts themselves have a more or less pronounced colour (e.g., chromium). Manganese in ammoniacal solution is oxidised by ferricyanide. The colour produced interferes perceptibly in ammonium tartrate solutions, while ammonium citrate eliminates interference even of higher concentrations of manganese.

The colour of the iron salts and chromium may be accounted for by using a compensation method, that is, by dividing the solution and adding ferricyanide to one half only. The blank solution without ferricyanide is first measured and then the colour solution. The first substracted from the second gives the extinction of the cobalt colour. Beer's law is not obeyed completely so that the standard curve is not linear.

The following method can be carried out in 25–30 minutes.

Method.

Solutions.

1. *Acid Mixture.*
    150 ml. sulphuric acid S.G. 1·84 and 200 ml. phosphoric acid S.G. 1·7 made up to 1,000 ml. with water.
2. *Ammoniacal Ammonium Citrate Solution.*
    250 gms. of citric acid dissolved in 250 ml. of water and 500 ml. of 25% ammonia added dropwise. The mixture is made up to 1 litre.
3. *Potassium Ferricyanide Solution.*
    25 gms. $K_3Fe(CN)_6$ dissolved in 80 ml. of warm water, cooled and diluted to 100 ml. The solution is stored in an amber dropping bottle.

0·2 gm. of steel chips are weighed into a 100 ml. measuring flask and brought into solution by heating with 10 ml. acid mixture. Five drops of concentrated nitric acid are added to oxidise the solution, which is then evaporated to fumes of sulphur trioxide. The mass is cooled and diluted with water, and 80 ccs. of ammoniacal citrate solution are added. The solution is cooled, made up to the mark and shaken. 50 ml. are added to a dry measuring flask and treated with 5 drops of potassium ferricyanide (which is sufficient for 15% Co). Both solutions are shaken and the absorption measured, using the Hg lamp and 530 filter. The percentage cobalt is then obtained from the standard graph.

Process for the Photometric Determination of Cobalt in Tool and High-Speed Steels in the Presence of Iron and other Alloying Elements

By G. Bogatzki

HITHERTO, four methods have been used in the photometric determination of cobalt in steel. In all these methods, iron and all alloying elements except manganese and nickel, are removed with a zinc oxide separation as in the usual gravimetric methods. The colour reaction is carried out in the resulting filtrate. Among the colours used were, blue cobalt chloride in concentrated hydrochloric acid, the red colour formed when hydrogen peroxide is added to an ammoniacal cobalt solution to give the cobalticammine complex, and the blue-coloured solution of the cobalt thiocyanate complex in acetone solution.

In this work, a colour reaction is used, in which the ammoniacal cobalt solution is treated with potassium ferricyanide solution to give a brownish-red complex, probably due to cobaltic ferrocyanide. The reaction has already been used by Dickens and Maassen in a potentiometric method for cobalt. These workers found that the potassium ferricyanide oxidises cobalt to the trivalent state with simultaneous reduction of ferricyanide

to ferrocyanide. Thus, a " potential jump " occurred at equimolecular proportions of cobalt and ferricyanide. The red compound thus produced may be used for the photometric determination. It was found that the absorption obtained on adding ferricyanide to cobalt solution was less than that obtained on adding cobalt solution to ferricyanide. The reason for this is not known. Also the colour stability was tested. The absorption decreases immediately after mixing solutions but after five minutes becomes constant and afterwards remains stable for a long period.

The addition of citric or tartaric acid prevents precipitation, but the concentration of ammonia must not exceed a given maximum figure, as a greater concentration causes decrease in absorption. In order to find out what influence the iron itself and other alloying elements have, solutions of iron, nickel, chromium, molybdenum, vanadium, tungsten, titanium and manganese were treated with citric acid, ammonia and potassium ferricyanide. In the presence of citric or tartaric acids and excess ammonia, iron gives complex salts which are green to brown in colour. No colour

Tungsten and Molybdenum Wire

By Irwin H. Such

METHODS employed for the drawing of tungsten and molybdenum wire at the Wickwire Spencer Metallurgical Company's works are discussed. The production of these wires involves one of the most unique processes in the metal-working industry, since it starts with chemicals and ends up with pure metallic material. The initial step in the production of tungsten wire involves a solution of sodium tungstate in water, precipitation of tungstic acid by the addition of hydrochloric acid, and conversion of tungstic acid to tungstic oxide in an oven. The tungstic oxide is converted to tungsten metal powder by reaction with hydrogen in gas-fired tube furnaces with three heating zones ranging from preheat of 900° F. to final temperature of 1,500° F.

Tungsten metal powder is formed into slugs ¾ in. square by 18 to 24 inches long in a hydraulic press. The slugs are fragile but are strong enough to be charged to a small furnace where they are sintered at 900° F. and are then heated to approximately 3,000° C. in cylindrical electric furnaces in which

the slugs serve as the heating elements. Subsequent drying operations involve working on hot swaging machines to convert the slugs into wire rods, and a series of drying and annealing operations—the number depending on the final size of wire specified.

Tungsten carbide dies are used in drawing larger sizes of wire and diamond dies for the smaller diameters. Annealing furnaces are atmosphere-controlled, electric-resistance type with pools of mercury at the entrance and exit ends serving as contacts.

Molybdenum is handled in much the same way as tungsten but the preliminary chemical operations are of course somewhat different. "Raw" materials for molybdenum wire are molybdenum trioxide and ammonium molybdate. These materials are reduced by hydrogen at 1,000° F., forming brown molybdenum oxide. The oxide is reduced at a temperature of 200° F. to metallic molybdenum powder which is pressed into bars and sintered at 2,300° C., or 300 degrees below the melting point for molybdenum. The bars are then reduced in the same manner as tungsten.

Anomalies of Graphitisation

By L. Crome

SILICON, the outstanding graphitiser, is, under certain conditions and perhaps acting indirectly, influential in forming or stabilising iron carbides. If a white iron containing 2·5% total carbon, 1% silicon, such as is used in the production of malleable iron, is given a ferro-silicon addition sufficient to cause the specimen to have a grey instead of a white fraction, and if this treated iron, along with one not treated with silicon and having all its carbon combined, be submitted to the normal malleabilising heat treatment, it will be found that the untreated metal will be completely graphitised, while the specimen with the silicon addition will come out with considerable carbides present. These carbides may be in the form of both pearlite and cementite and, if the latter, give the impression that they may have been formed from the coalescence of the cementite plates in pearlite.

The outer part of the silicon treated specimen will be rather badly deterio-

rated, having no strength and a microstructure that resembles none of the familiar iron carbide structures. Next to this outer layer will be the carbides which may be in a band of varying width or may extend to the centre, depending on the length of time and other conditions of the heat treatment and also on the amount of primary graphitisation. Experiments show that the higher the temperature and the longer the time, the deeper the stabilised zone penetrates towards the centre, and also that, if specimens are withdrawn from the high temperature exposure (870° to 925° C.) and later given a short low temperature treatment (5 hours at 540° C.) to decompose the pearlite, the specimens with a short exposure to the high temperature will graphitise completely except for traces of carbide at the surface, while the specimens with a longer exposure will remain more or less stable.

If the malleabilising treatment is carried out in a tight container with charcoal so as to have an atmosphere composed essentially of carbon monoxide and inert nitrogen at the high temperature of the cycle, the phenomenon will not occur or, at any rate, to no appreciable extent and similarly, if the treatment is carried out in air with no large amounts of oxides of carbon in the atmosphere, it occurs only to a limited extent. If, however, the malleabilising treatment is carried out in the atmosphere of the products of combustion, an atmosphere with a relatively high carbon dioxide content, the phenomenon occurs to a large extent, indicating that carbon dioxide plays an important part in the carbide stabilisation. The heat treatment experiments have also shown that a penetration of carbon dioxide into the metal in some manner is essential.

Normal cupola melted grey iron, both with and without ladle additions of ferrosilicon, carried through the same heat treatments, do not react the same as the grey iron produced from white iron by ladle additions of ferro-silicon. In many cases the cupola melted grey irons show no noticeable carbide formations, although they deteriorated markedly in the high temperature exposures in all three atmospheres.

Another anomaly of graphitisation occurs with aluminium, which is also a powerful graphitiser. Additions of aluminium in small amounts, in some cases just a few one-hundredths of 1%, to white cast iron such as is used in the production of malleable cast iron, will cause some primary graphitisation and will be helpful in promoting decomposition of pearlite in the second stage of the malleabilising process. However, aluminium ladle additions in the amount of 0·04% or more, whether or not any primary graphitisation occurs, frequently results in metal with sparkly fractures and retaining appreciable amounts of small carbide nodules, while processed along with it a similar specimen with no aluminium or a smaller amount, will have a normal black fracture and be free of all carbides. This phenomenon is more pronounced in some sections than in others, indicating that cooling conditions in the mould have an effect on it.

Amounts of aluminium greater than 0·04% do not seem to be either more or less effective in retaining some cementite. Larger amounts, such as 0·3%, while producing appreciable primary graphite and assisting or at least not hindering, the decomposition of pearlite, will frequently allow appreciable cementite to remain while a similar specimen without aluminium will be free of carbides.

Forming Stainless Steel with Zinc Alloy Dies

By W. W. Broughton

THE austenitic 18–8 steels are the most widely used of alloys in the stainless group, and in spite of their hardness and strength have greater ductility than the average deep drawing mild steel. Difficulties of fabrication lie not so much in the ability of the material to reach a desired end result, as with the means or method by which the result is obtained. As greater power is required to form stainless steel than mild steel, it follows that die design, gauge and surface conditions of the sheet and effectiveness of lubricants are critical factors affecting forming operations. If zinc alloy dies are used in these operations, any pick-up of zinc from them must be removed by acid pickling or the steel becomes brittle upon being subjected to elevated temperatures.

In the manufacture of aircraft engine manifolds and jet engine components of 18–8 austenitic steels in which the shapes of stampings that

form the manifolds and such components are varied and complicated, dies of a zinc-copper-aluminium alloy (Kirksite A) having physical properties far below those of the steel being formed have been used with either the mechanical press, the hydraulic press or drop hammer. In the production of a typical component (exhaust part), a starter die in three parts is used on a 200-ton mechanical press and from it is produced a stamping whose exact shape is determined by experience from how much deformation the steel will take without failure. After annealing, the partly formed piece goes to a " finish " or " full " die in the drop hammer, where one blow is usually sufficient to produce the desired final shape.

Many deep drawn parts are produced on the drop hammer alone with a single punch, by limiting the depth of draw. In this operation the die is set up in the hammer and a layer of antimonial lead poured over its surface and allowed to freeze immediately so as to

build up a pad which is thicker in the deepest points in the die cavity than in the shallow points. The original pad of lead alloy is stripped from the die and replaced by a second thinner pad which allows the steel to be drawn somewhat deeper. After the parts have been struck they are run through the zinc alloy die with no lead pad, giving the part its final form. Some parts require several redraws, others just one intermediate stage.

The technique of producing the special zinc-copper-aluminium alloy dies consists in making separate plaster patterns for each member of the die set, allowing for metal thickness between punch and die and also between punch and pressure pad. From these accurate patterns, castings are produced, which can usually be sent direct to the press room for trial, and the shape of the trial-stamping determines whether or not fitting is required on the dies. The final die pattern is always made first and, if it is found that the stainless steel cannot be formed to its final desired shape using only the final die, stage dies are produced. The special zinc alloy has also been used for producing press and blanking dies, but in the case of the latter the alloy in sheet form is not

suitable for blanking steel heavier than 0·015 in. thickness, because of the physical properties of the materials used.

The advantages of zinc alloy dies over steel dies for production applications are, in general, reported to be that they are much less expensive and can be produced in a matter of hours, as against days for steel dies, so that frequent changes in design or experimental production can be accomplished without prohibitive delays. The skilled diemakers required for making steel dies are not required in the manufacture of zinc alloy dies, nor is much close machining required to finish the cast dies to close dimensional tolerances. Other advantages of importance are the accuracy of casting that is possible with zinc alloys, often obviating machining of the cast alloy; the elimination of die scratches on work by virtue of the zinc alloy's softness; and the reclamation value of the zinc alloy which is almost 100% re-usable by simply remelting under proper conditions.

Zinc alloy dies are made either as sand castings, plaster mould castings or rolled sheet, depending on the purpose for which they are to be used.

TABLE I.—APPLICATIONS OF ZINC ALLOY DIES

Operation	Material	Gauge	Number of Parts or Blanks
Forming	Armour plate	⅛ in.	Several hundred
	Stainless Steel	0·091 in.	400
	Stainless Steel	0·038 in.	2,800
	Body stock steel	0·089 in.	1,200
	Body stock steel	0·037 in.	18,000
Blanking	Stainless Steel	Up to 0·050 in.	100
	Body stock steel	0·062 in.	1,800
	Duralumin	0·032 in.	30,000

Most soft alloy stampings, forming and drawing dies are cast, usually in sand; dies for certain plastic moulding operations are cast in plaster moulds, as are some stamping dies; while dies made from rolled zinc alloy sheets are used for many blanking, forming and trimming jobs.

Generally, zinc - copper - aluminium alloy dies are regarded as low-cost dies, useful for moderate production runs. They cannot be used to replace steel or cast iron dies on all or even most of their established applications. In Table I. are given some of their applications and the number of parts involved in the lot or the number made before failure. These applications show either the thickest gauges or the longest runs made with zinc alloy dies.

Comparative Properties of Cast and Forged Steel

By C. E. Sims

THE tremendous war-time demand in aircraft production for forgings of all types, drop forgings, machine forgings and hammer forgings, developed a shortage in forging-quality alloy steel in forging machine capacity, in die block steel and in toolmakers. As a result, forgings were extremely hard to procure in a reasonable time, especially when changes in design required new die blocks, and when some parts were of such size and shape as to require complicated and expensive dies. The substitution of steel castings for forgings was suggested, but as the comparative properties of the two products were largely unknown in the aircraft industry, research work was initiated at the Battelle Memorial Institute to determine the relative properties of the two materials.

Early in the investigation, a request was made to compare the properties of forged and centrifugally cast aircraft engine cylinder barrels, especially in fatigue. Tensile and fatigue tests were taken longitudinally and transversely from one forged and two

centrifugal cast cylinder barrels heat-treated by quenching in oil from 845° C. and tempering back to a hardness of approximately 325 Brinell. The tensile results are given in Table I. together with the compositions of the steels. The fatigue tests which were carried out both on smooth and square-notch test bars, were tested on a rotating beam machine to 7 million

cycles and gave S–N curves of a very similar type.

Another method proposed to relieve the strain on forging facilities was to cast forging blocks that would approximate, in shape and size, to the rough forging before it entered the last impressions of the die block. By doing so, smaller die blocks with fewer impressions would be required and hot working would improve the mechanical properties of the part so that it would more closely resemble forged steel than cast steel, particularly if the castings were not originally sound. To investigate such a process, 1¼ in. square steel bars with carbon contents, ranging from 0·24 to 0·42%, were cast. Half of the bars were cast sound, while the rest were purposely cast with a bad centre-line shrinkage. Part of these were forged lightly and then all were heat-treated and machined to tensile and Charpy test bars. The average properties for all the conditions obtained are given in Table II. and show a considerable improvement produced by light forging in the unsound bars and a lesser improvement in the properties of the sound cast bars. Etching showed that the forging tended to close shrinkage cavities.

To obtain a more comprehensive test, an aircraft part from a wrought steel block was used as a model for a pattern which was made very similar to the finished forging, except that it was oversize in the vertical direction. Castings made from the pattern were then forged in the same die-block as the model. One cast and one cast-and-forged specimen from each of 3 heats were heated to 1,010° C. for 4 hours and air-cooled, reheated to 900° C. for 2 hours and water-quenched, and then tempered at 510° C. and air cooled. Brinell hardnesses obtained from these bars ranged from 331 to 341, and

TABLE I.—COMPOSITION AND PROPERTIES OF CYLINDER BARRELS.

Condition	Composition				Orientation	Yield Point Tons per sq. in.	Ultimate Stress Tons per sq. in.	Elongation %	Brinell Hardness
	C	Mn	Cr	Mo					
Forging	0·41	0·74	0·89	0·29	Longitudinal	39·4	60·5	13·4	323
					Transverse	47·7	63·3	11·7	325
Casting	0·42	0·74	0·93	0·18	Longitudinal	42·5	61·8	13·2	324
					Transverse	42·0	61·4	11·7	324
Casting	0·45	0·86	1·06	0·29	Longitudinal	56·3	70·0	13·3	321
					Transverse	52·0	68·5	13·3	321

TABLE II.—PROPERTIES OF SOUND AND UNSOUND CASTINGS AND FORGINGS.

Condition	Ultimate Stress Tons per sq. in.	Elongation %	Charpy ft.-lb.	Brinell Hardness
Cast unsound	54·7	1·5	12·5	320
Cast sound	64·8	12·5	16·5	313
Cast unsound, forged	66·6	10·5	18·5	316
Cast sound, forged	68·2	15·5	22·5	320

tensile and impact (Charpy) tests showed a general improvement in the mechanical properties as a result of forging. There was also a marked improvement in soundness, but this improvement could not be relied upon to eliminate defects in unsound castings.

An investigation was also carried out on the comparative qualities of seamless tubing from centrifugal castings and from pierced billets. Centrifugally cast hollow cylinders, $4\frac{1}{4}$ in. and $3\frac{5}{8}$ in. outside diameter, were cast from a carbon-chromium-molybdenum steel (S.A.E. 4130). The $4\frac{1}{4}$ in. castings were hot-rolled to 4 in. and then cold drawn to $3\frac{1}{2}$ in. outside diameter, while the $3\frac{5}{8}$ in. castings were hot-rolled

to $2\frac{1}{2}$ in. and then cold-rolled to 2 in. outside diameter. Specimens of both tubes were then examined, together with specimens of regular production tubing of similar size, from pierced billets, when it was found that so far as the surfaces were concerned, there was very little difference, but that the inside surface was better on the specimens from pierced billets. In standard (A.S.T.M.) flattening tests, both types of $3\frac{1}{2}$ in. tubes showed equally good properties, while both types of 2 in. tubes failed. In a non-standard reversed flattening test, the pierced 2 in. tubes gave a better test. Tensile test specimens cut from the tubes showed equal mechanical properties.

The Ignition of Solid Magnesium Alloys
By L. A. Carapella and W. E. Shaw

THE greatest factor controlling the wider application of magnesium alloys has been the common misapprehension that these alloys are highly inflammable and that products fabricated from them are potential fire hazards even at slight exposure to heat. Tests have therefore been conducted on a number of commercial magnesium alloys to ascertain their general behaviour upon direct exposure to fire. Testing procedure was to apply an intense flame from a torch to a small specimen until ignition resulted. The temperature was measured with a fine wire thermocouple carefully embedded in the ignition zone and a direct reading pyrometer. Evidences of metal flow were observed in all cases just prior to burning and the average ignition temperature from a number of observations made on each alloy is given in Table I. together with their respective solidus and liquidus temperatures derived from reliable sources.

A comparison between the ignition and melting temperatures for the magnesium alloys under consideration shows that melting is positively a prerequisite of burning. Of supplementary importance is the fact that the presence of only $0 \cdot 001\%$ of beryllium retards the burning of the A.S.T.M. 4 magnesium alloy in a molten condition. A very tenacious film appeared to be formed upon heating the alloy and this film protected the molten metal and caused burning to occur only at very high temperatures. Calcium around $0 \cdot 05\%$ is claimed to have a similar retard effect on the burning of

magnesium alloys. Massive magnesium alloys are also very difficult to ignite owing to their relatively high heat conductivity. Magnesium dusts, like dusts from certain other metals, are easily burned because of the comparatively small amount of heat required to attain the ignition point.

TABLE I.—THE MELTING AND IGNITION TEMPERATURES OF SOME MAGNESIUM ALLOYS

Alloy Type	Melting Range		Approx. Ignition Temperature °C.
	Solidus °C.	Liquidus °C.	
Pure Magnesium ..	650	650	650
ASTM 4 (AZ 63) ..	440	610	580
ASTM + 0·001% Be	440	610	>800
ASTM 8X (AZ 61X)	460	615	500
ASTM 11 (M2) ..	645	648	650
ASTM 17 (AZ 92) ..	435	596	450
Mg + 2% Si (82X)	645	600	650
MG + 6% Al(A6X)	590	630	610
Commercial Magnesium Cooking Griddle	645	648	650

Titanium in Chrome-Manganese Stainless Steel
By G. F. Comstock

RECENT research has shown that titanium in even small amounts has a very useful effect on 17% manganese 12% chromium stainless steel in raising the yield strength. Even with as little as 0·14% titanium the yield strength is increased appreciably, or 15 to 20% when tempered after quenching. With about 0·75% titanium a yield strength above 48,000/in.^{2} is developed in this steel by heat-treatment alone, comparing with a

normal value of about 32,000/in.^{2} in ordinary stainless steel not cold-worked. And with this higher yield strength, the ductility and impact resistance are not impaired, the hardness being not much greater. With about 1% titanium, the yield strength is almost up to the same high value in the quenched condition without tempering, and on tempering the ductility and notch toughness are decreased. With still higher titanium contents, up to 1·6 or 3% hardness values of 40 to 60 Rc can be obtained by temperhardening, but such steels are either not forgeable or lacking in notch toughness. Temper-hardening of these steels with titanium is thus not especially attractive, for with less than 1% titanium there is but little increase in hardness, and with more titanium the hardened steel may be brittle. Temper hardening seems to depend on the formation of a ferrite structure, replacing the normal austenite. With less titanium than is required for temper-hardening, however, or for changing the structure completely to ferrite, the quenching and tempering heat-treatment is very useful for increasing the yield strength value 20 to 50% higher than in ordinary non-titanium stainless being obtainable in the titanium steels by heat-treatment alone without cold working.

Spot Test for Aluminium and Manganese Bronze
By L. B. Corbett

FOR salvaging purposes a speedy test has been developed to aid sorting of aluminium bronze from manganese bronze. A small area on the bronze part is cleaned of all dirt, scale and grease by grinding. The area is then sprayed with a sulphuric acid solution by a simple device consisting of the glass tip of a medicine dropper, a rubber pressure bulb, a rubber-stopper bottle containing the solution and a small-bore glass tube extending through the stopper to impart the spray. After a few seconds an indicator solution is applied from a medicine dropper, consisting of varied weights of ammonium-mercury thiocyanate, silver nitrate and ammonium persulphate. Immediately a coloured spot appears—a grayish purple, for manganese; greenish-yellow, if aluminium. Since only one drop of indicator is needed per test, 50 cm.^{3} of indicator serves for many tests.

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